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Andeen et al.

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(54) **PLATFORM POSITIONING SYSTEM**

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Related U.S. Application Data

(63) Continuation of application No. 09/543,265, filed on Apr. 5, 2000, now Pat. No. 6,355,994, which is a continuation of application No. 09/543,283, filed on Apr. 5, 2000, now Pat. No. 6,471,435.

(60) Provisional application No. 60/163,846, filed on Nov. 5, 1999.

(51) **Int. Cl.**[7] **F16B 1/00**

(52) **U.S. Cl.** **250/492.2**; 250/310; 403/220; 378/34; 355/53

(58) **Field of Search** 250/492.2, 310; 378/34; 414/354; 355/53

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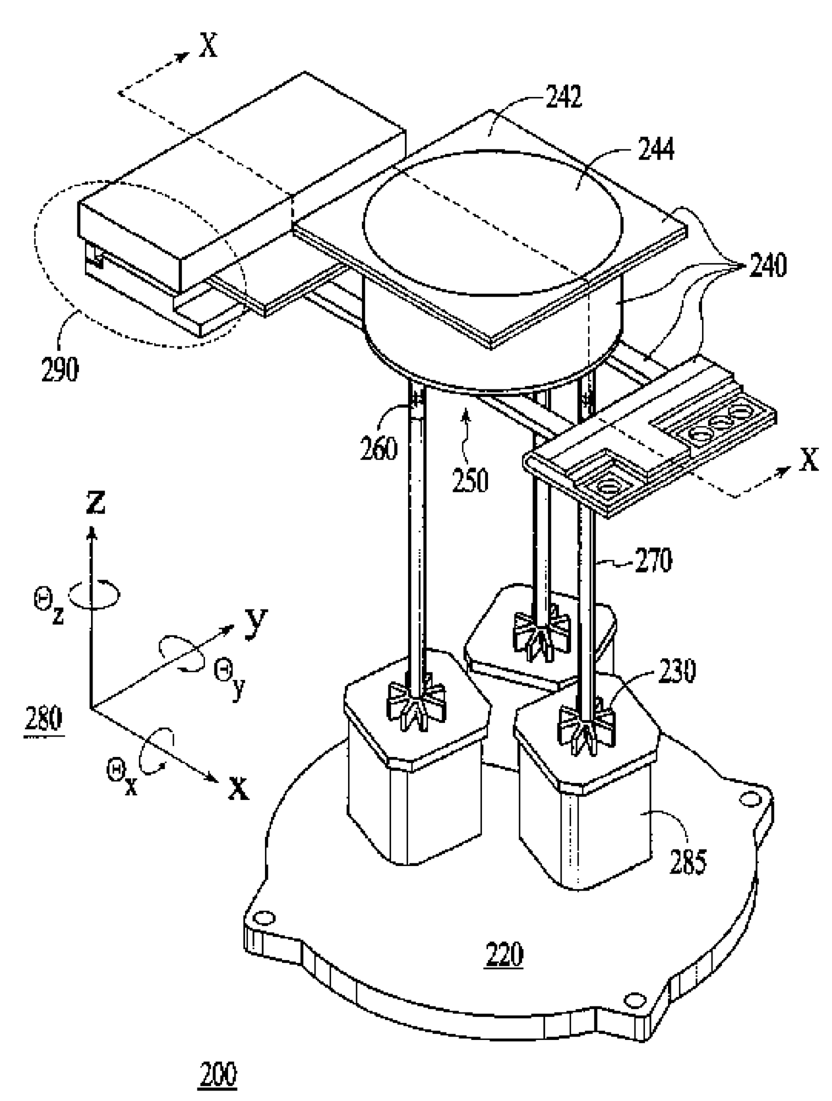
(57) **ABSTRACT**

A system for precisely positioning and moving a platform relative to a support structure is disclosed herein. The platform is particularly suitable for carrying wafers. Charged particle optics can be attached to the support structure. The platform positioning system comprises a stage, comprising a base, a platform and stage actuators, the stage actuators being coupled to the platform and the platform being coupled to the base; a frame attached to the base; a support structure mechanically coupled to the frame; stage sensors attached to the support structure, for sensing the position of the platform relative to the support structure; and a current control system coupled to the stage sensors and the stage actuators. The current control system may include a predictor for generating an ouptut signal anticipating the actual position of the platform relative to the support structure in real time.

23 Claims, 24 Drawing Sheets



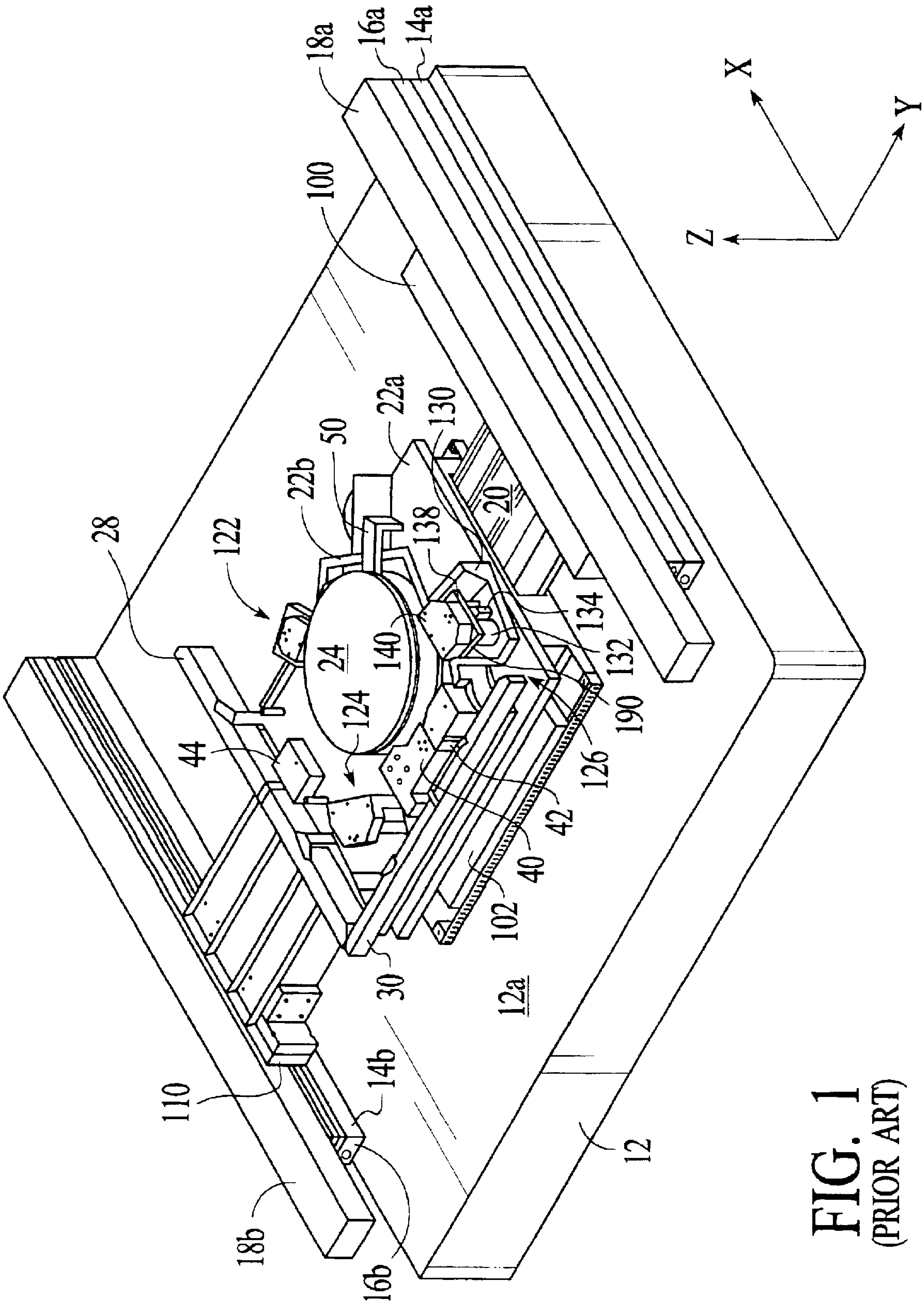


FIG. 1
(PRIOR ART)

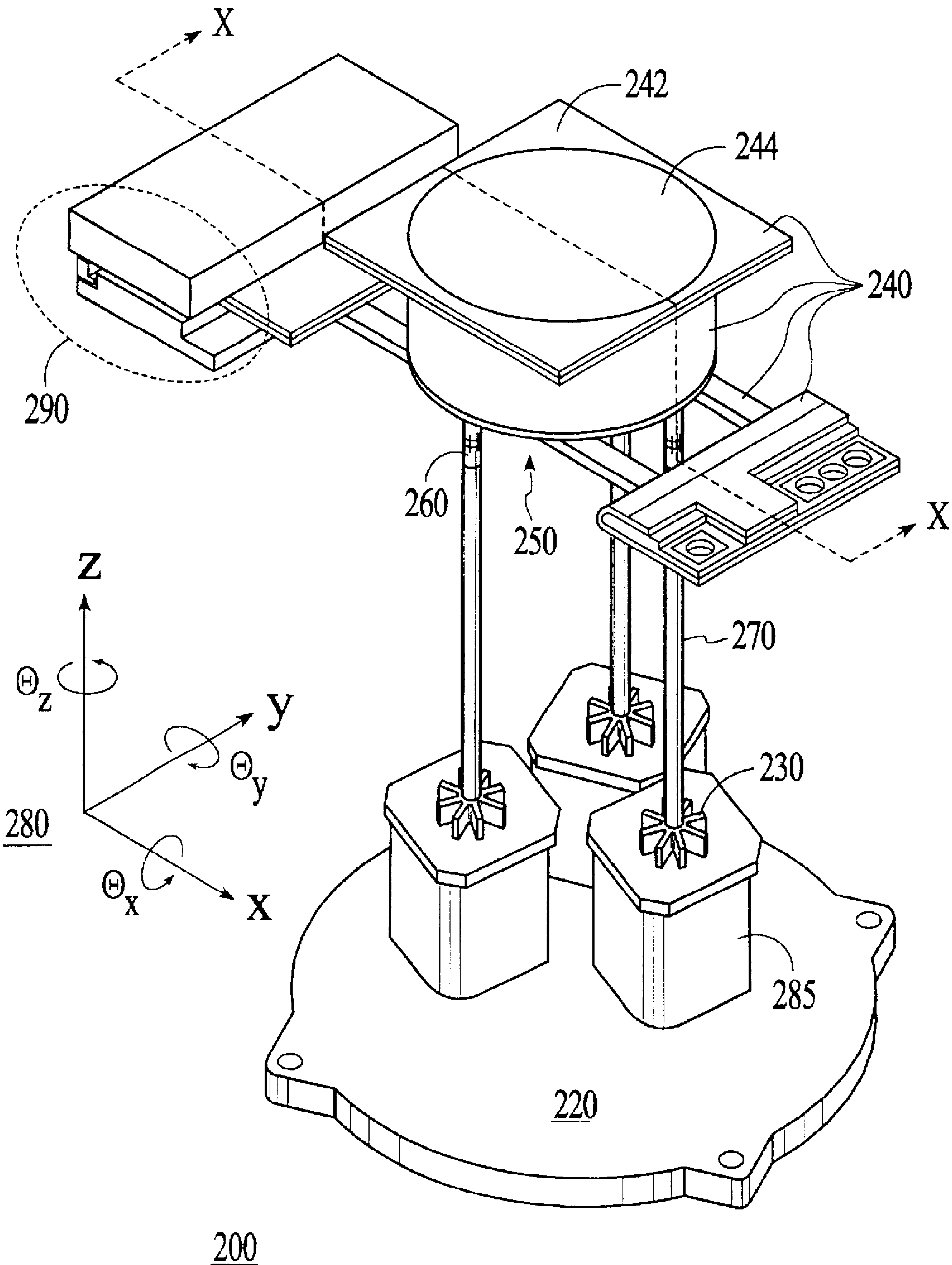
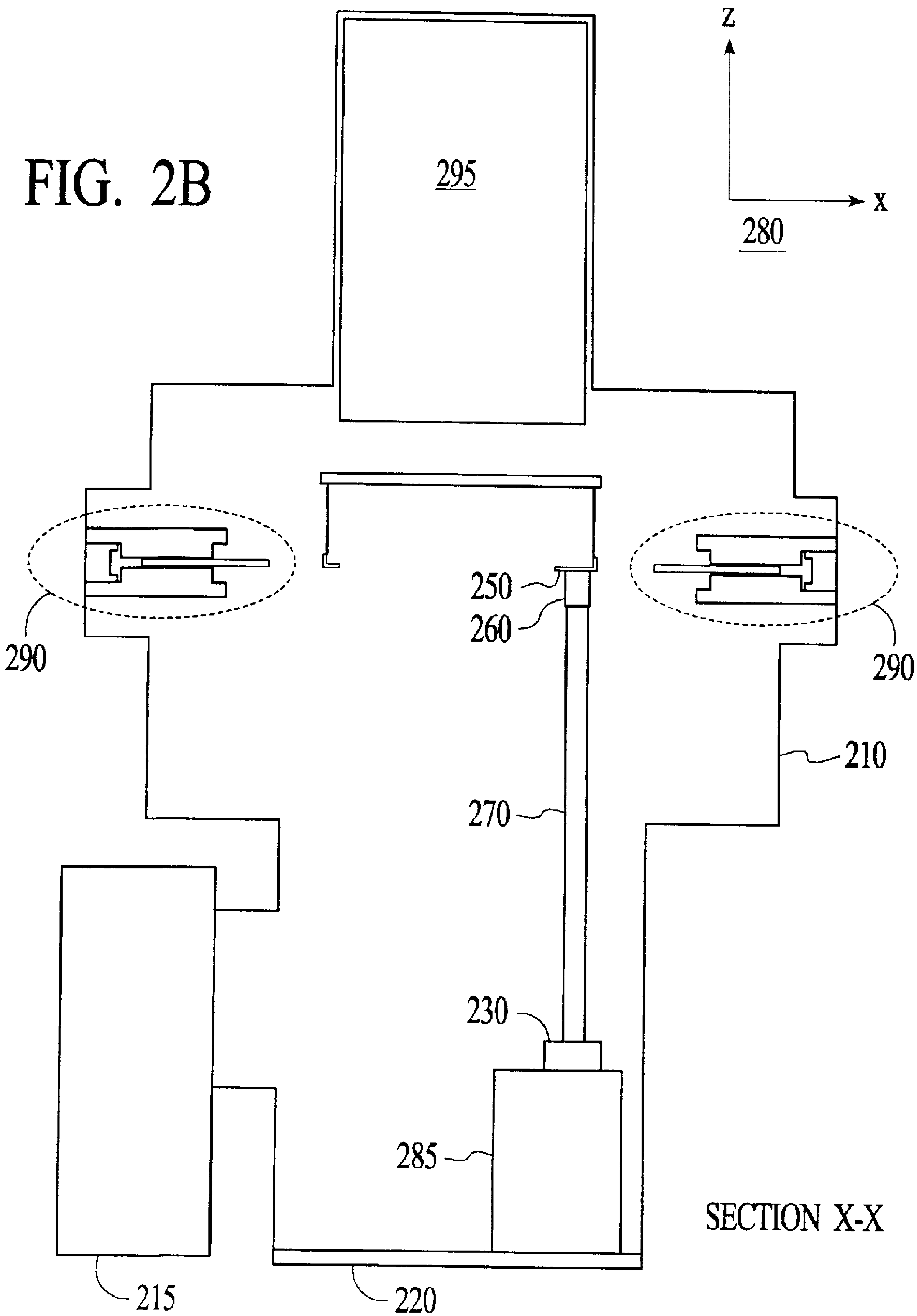


FIG. 2A

FIG. 2B



SECTION X-X

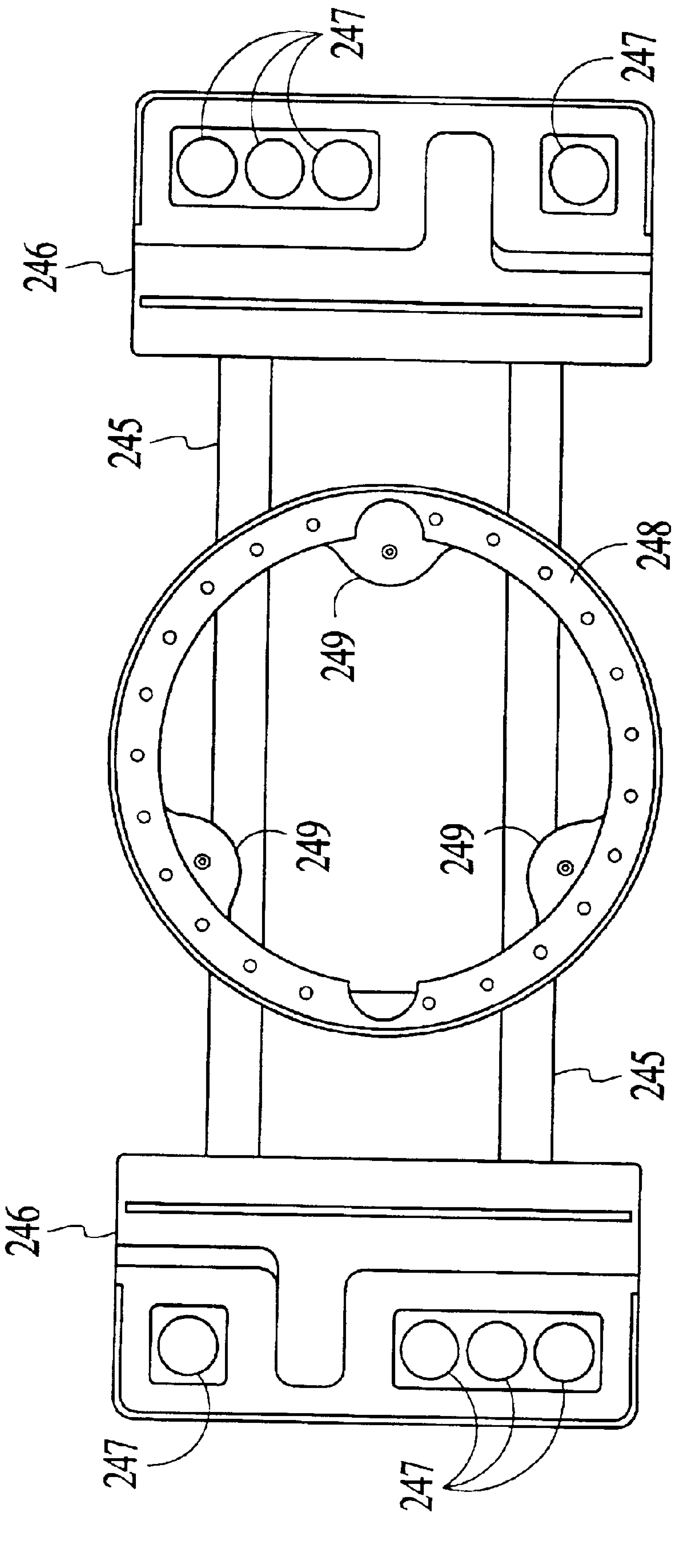


FIG. 2C

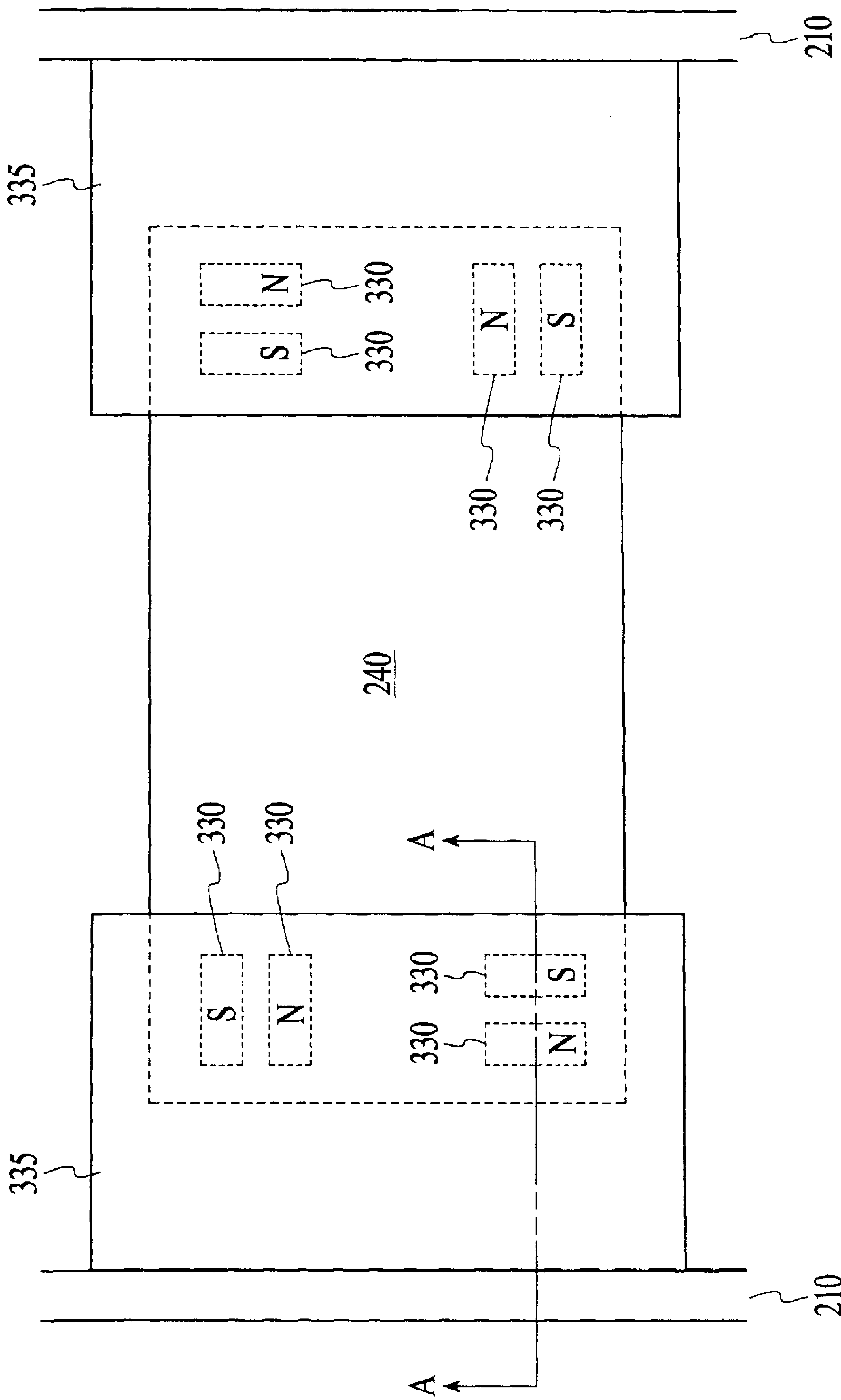


FIG. 3A

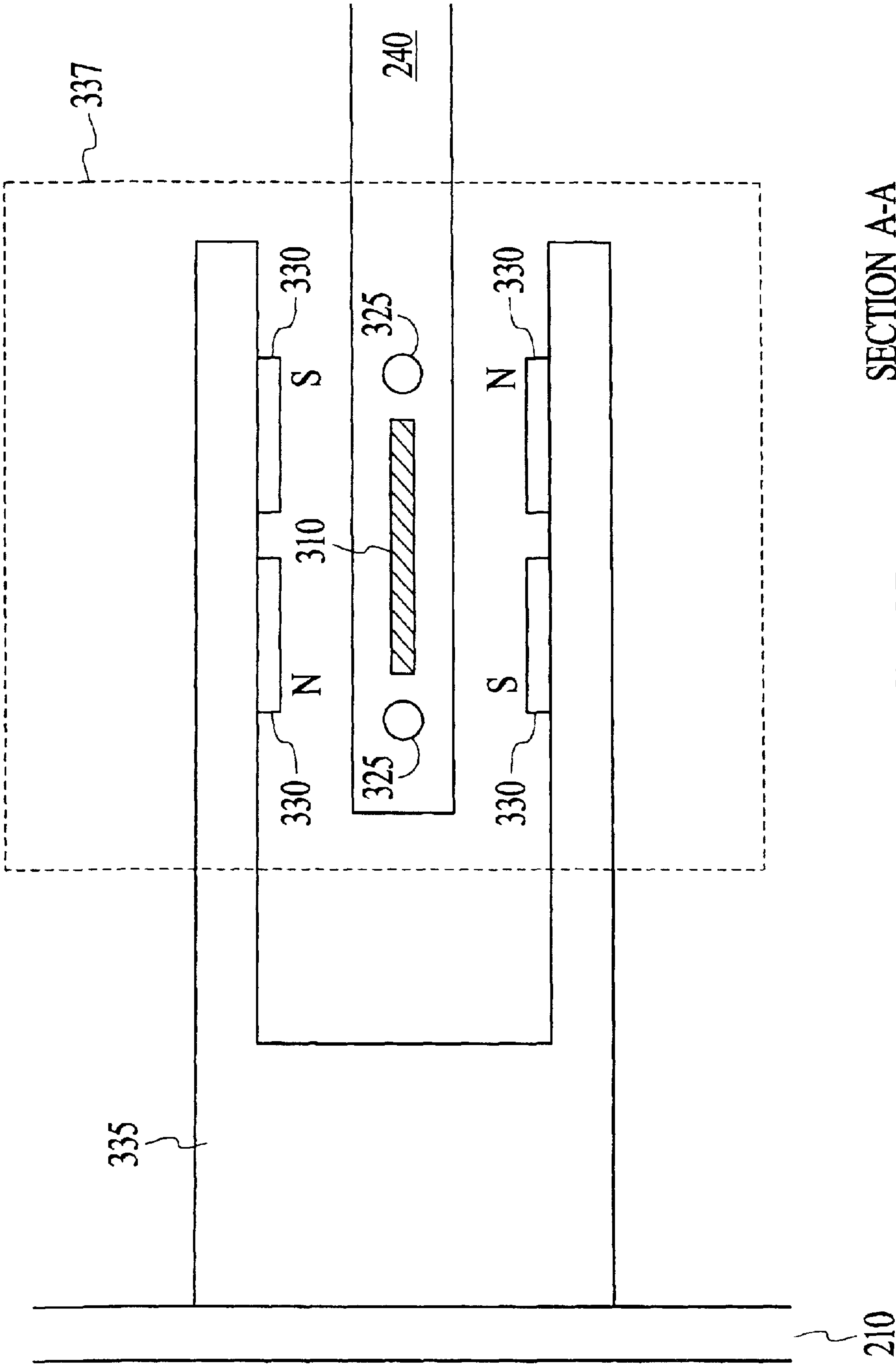


FIG. 3B

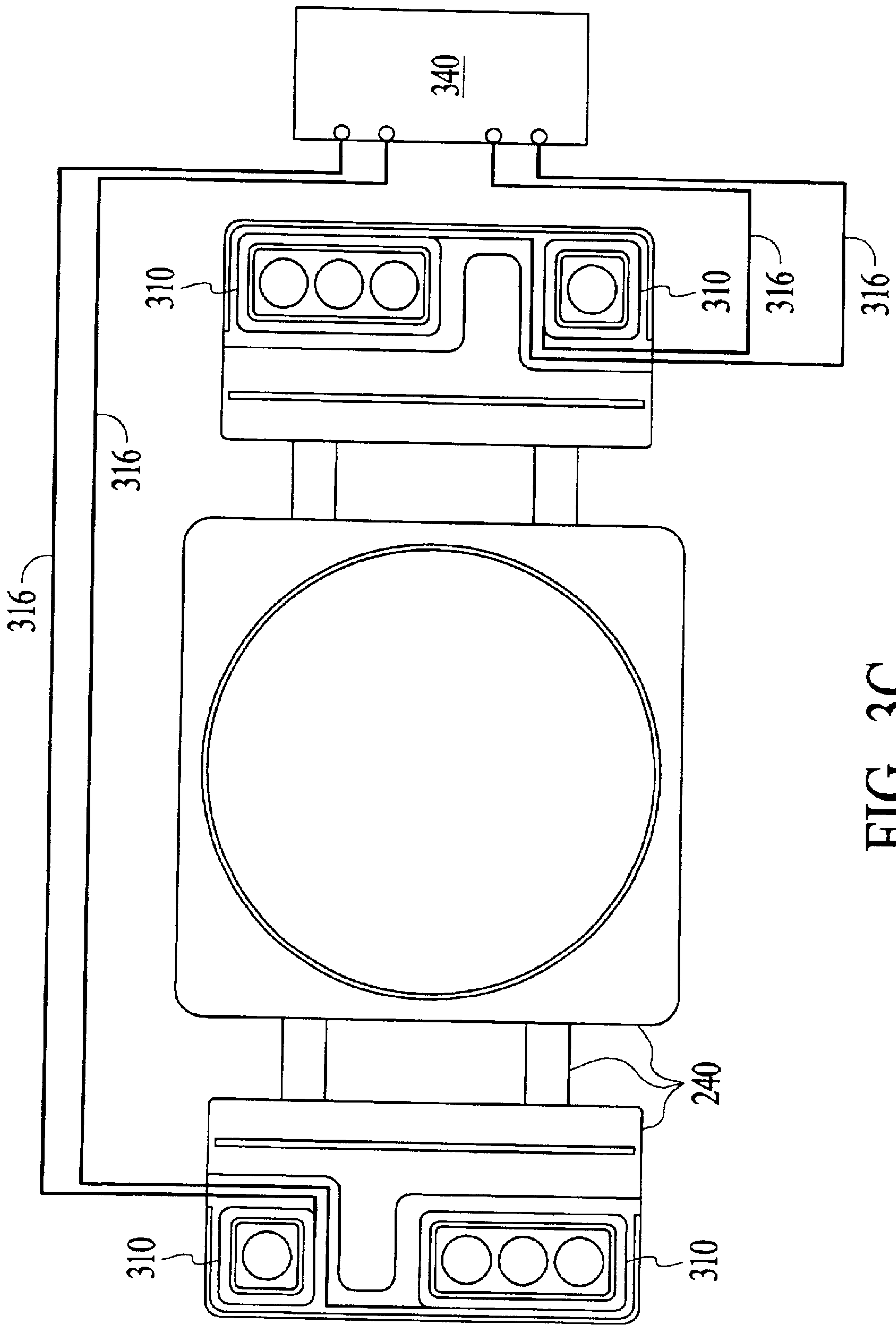


FIG. 3C

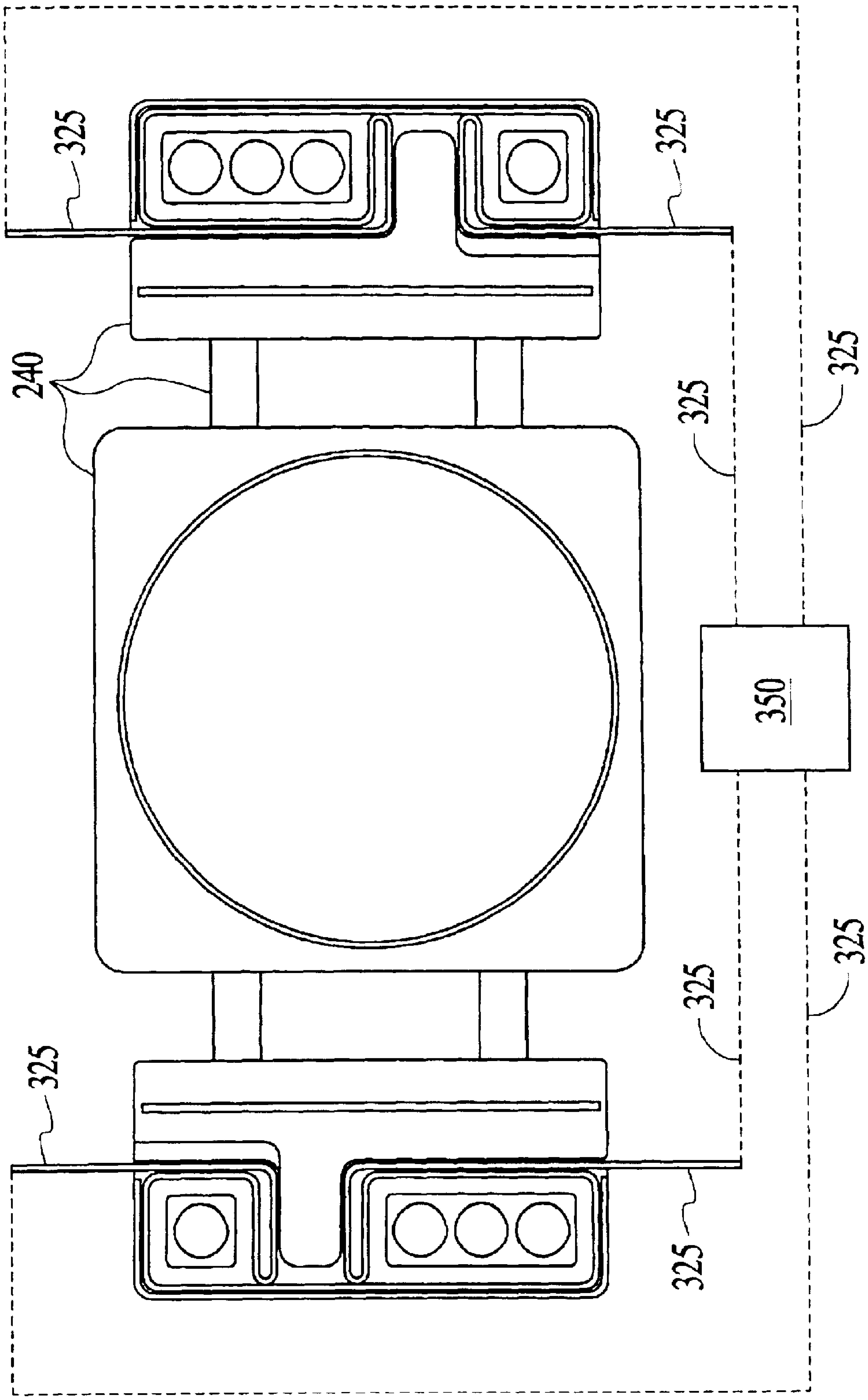


FIG. 3D

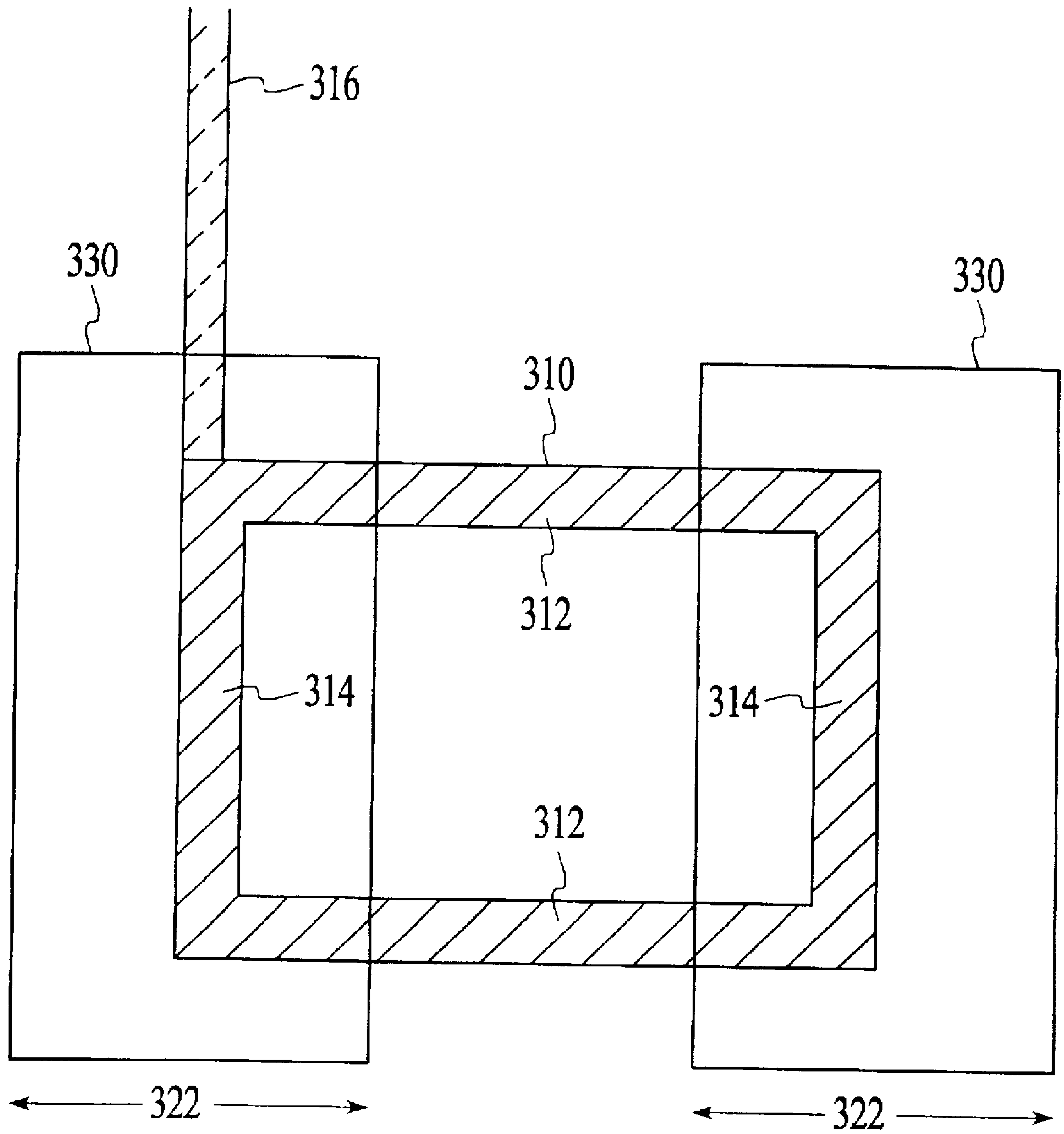
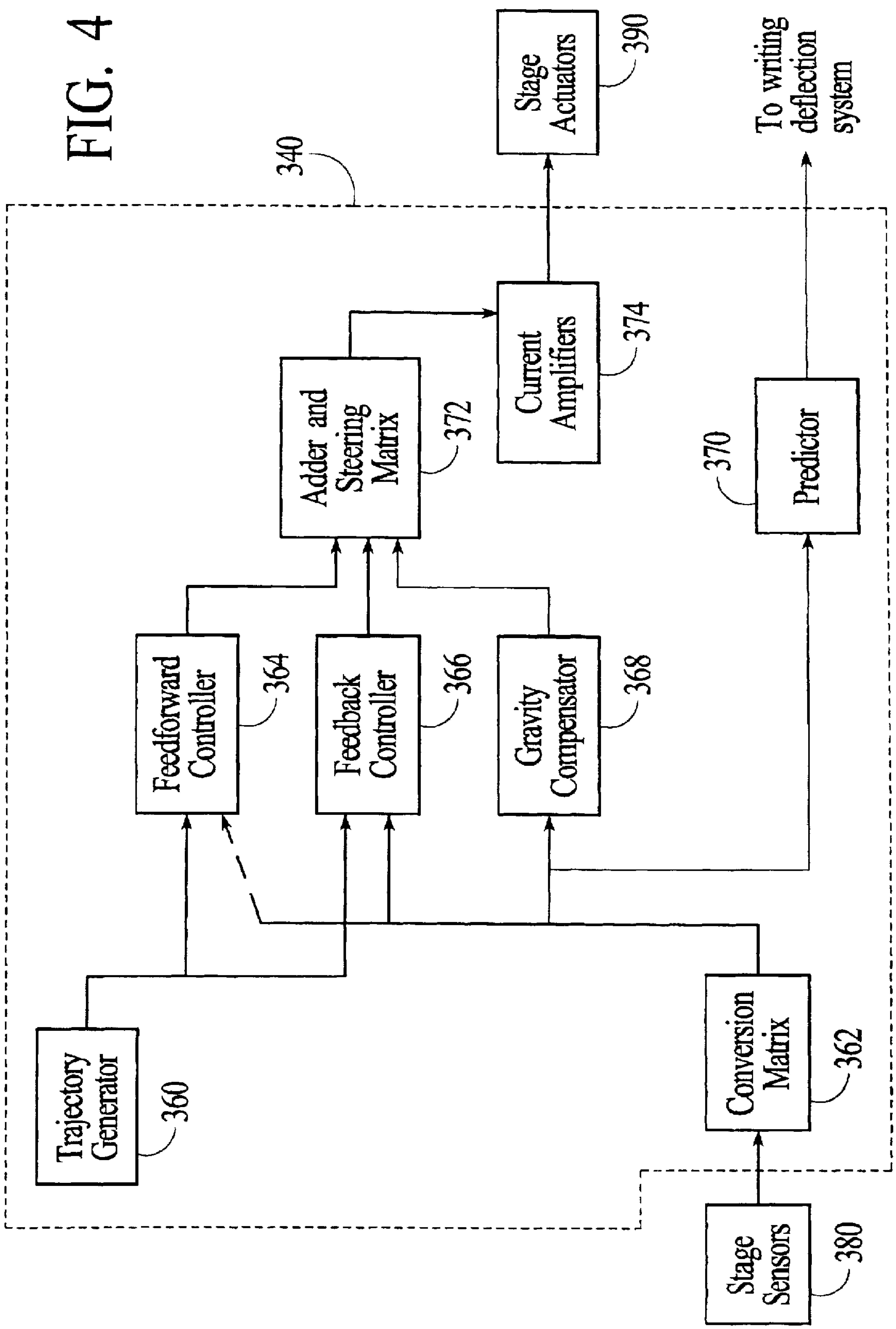


FIG. 3E

FIG. 4


340
Trajectory Generator
360
Feedforward Controller
364
Feedback Controller
366
Gravity Compensator
368
Adder and Steering Matrix
372
Current Amplifiers
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Stage Actuators
390
Predictor
370
To writing deflection system
Conversion Matrix
362
Stage Sensors
380

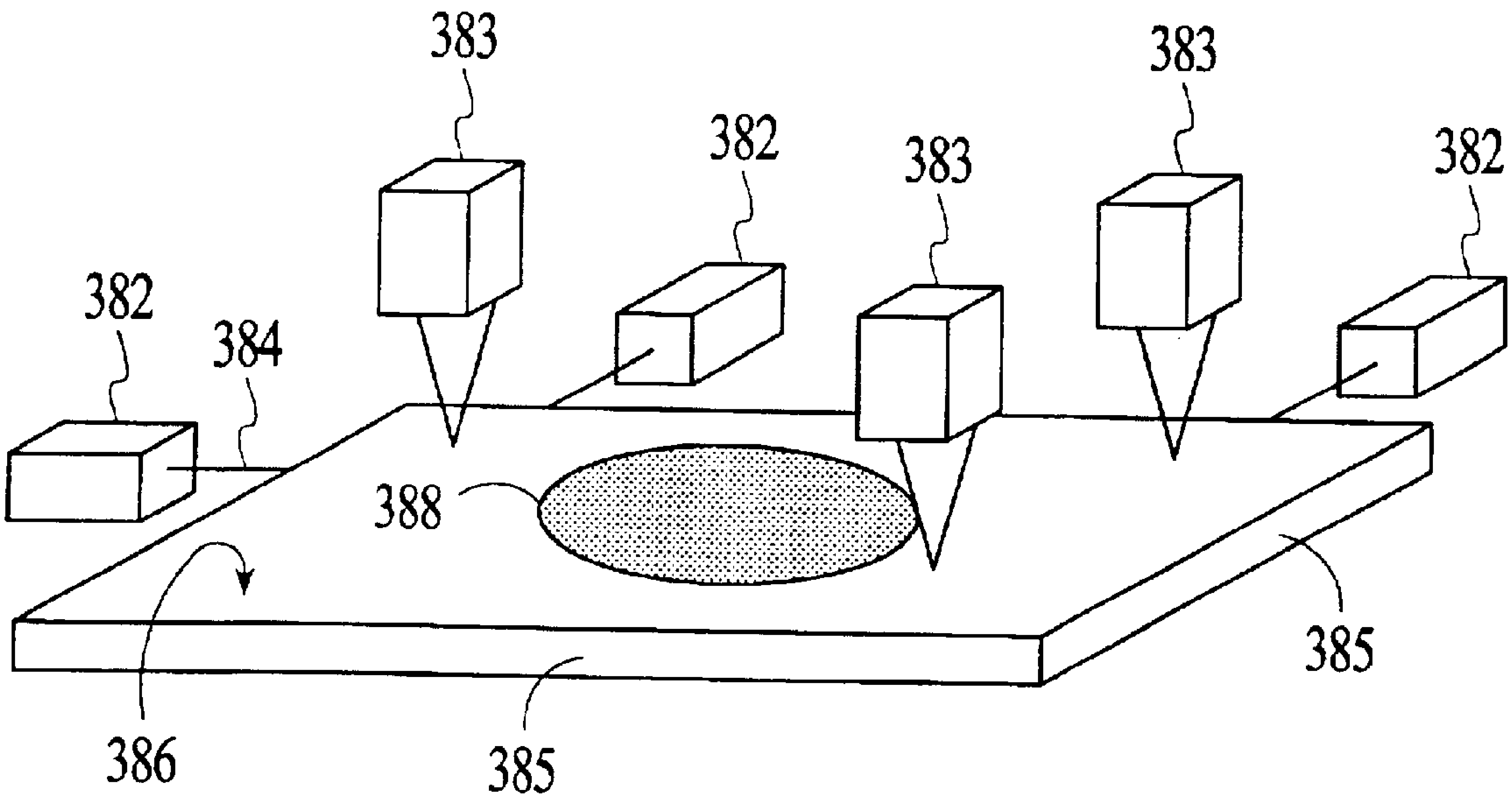

FIG. 5

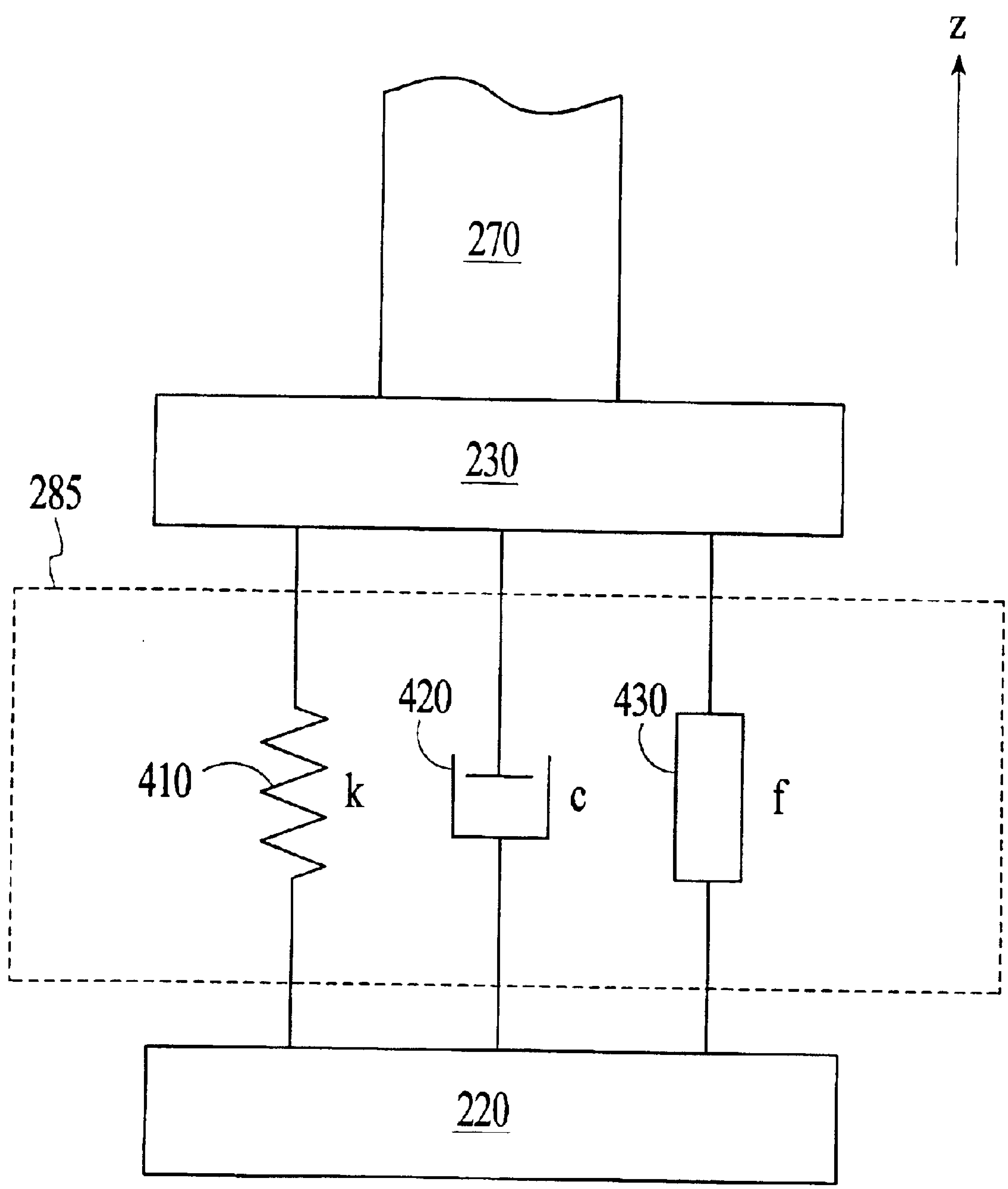

FIG. 6A

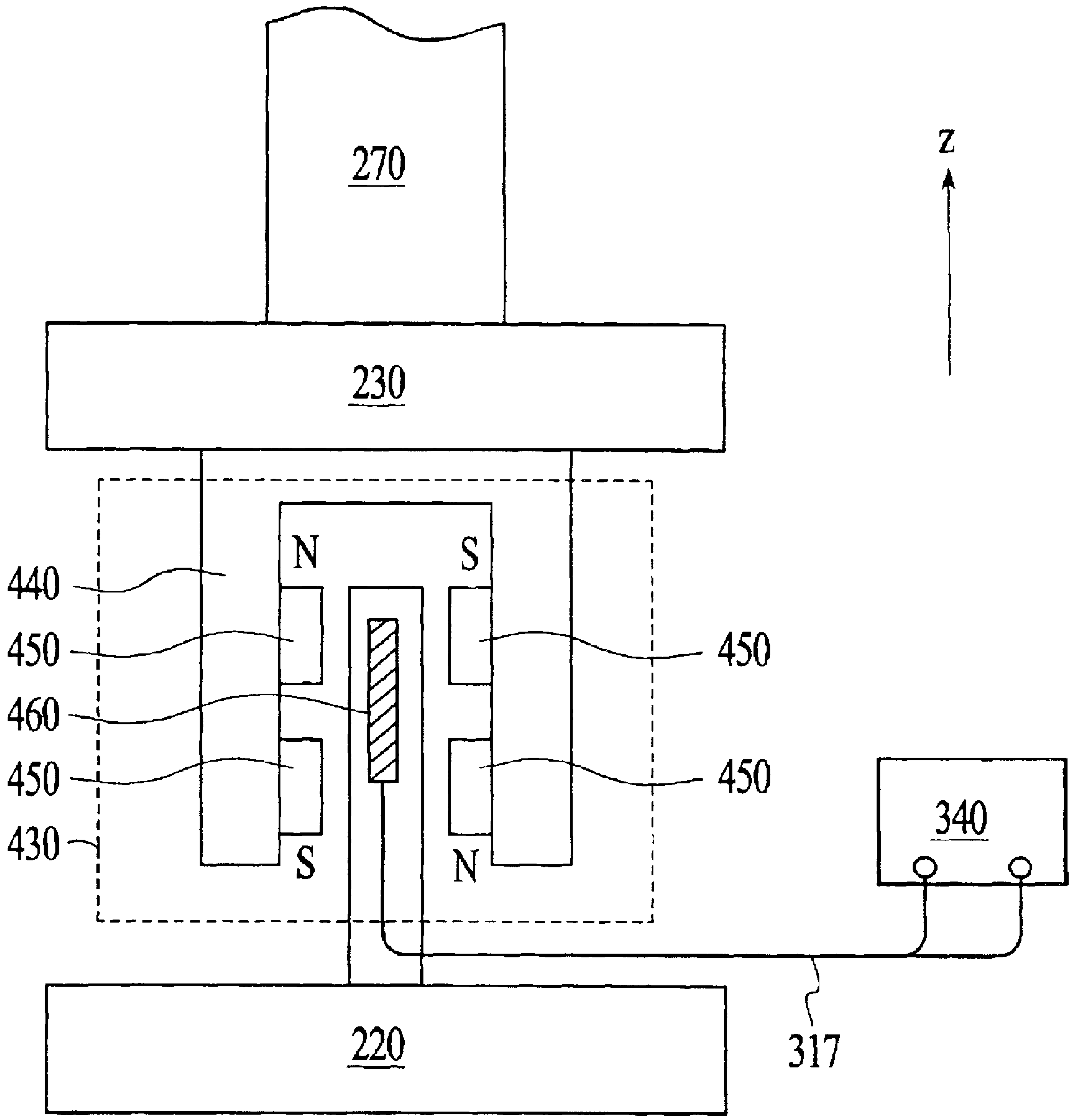

FIG. 6B

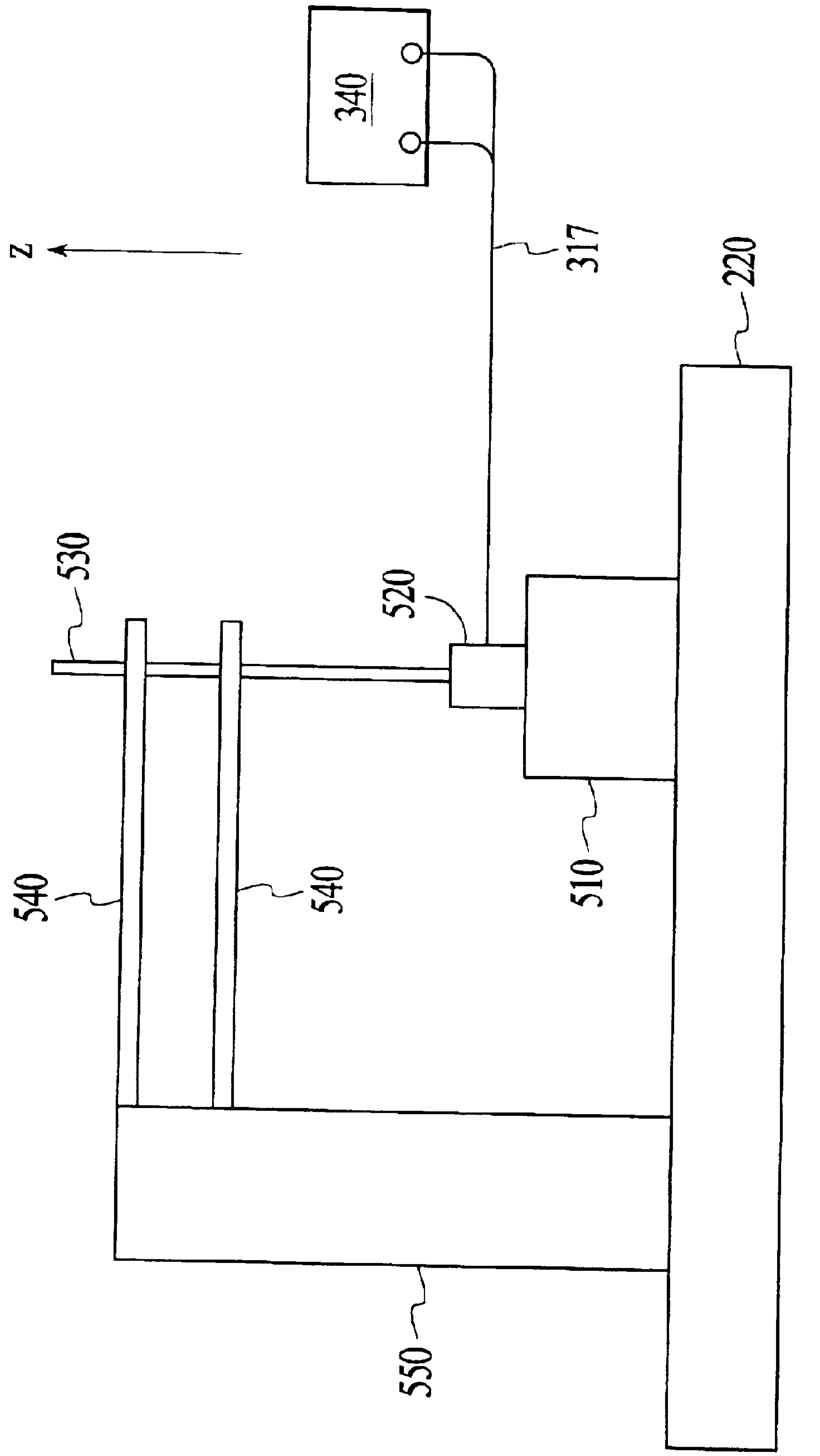

FIG. 6C

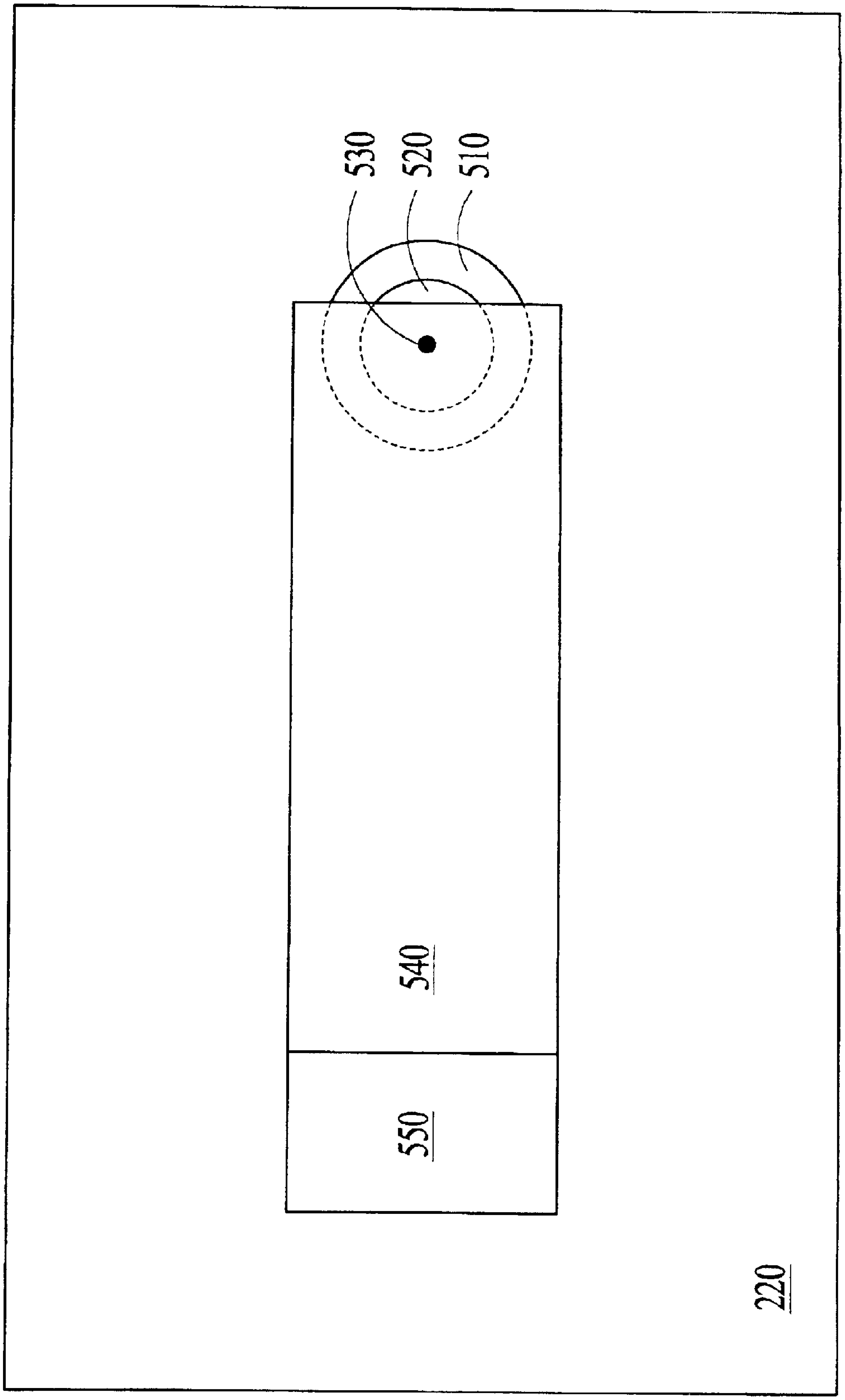

FIG. 6D

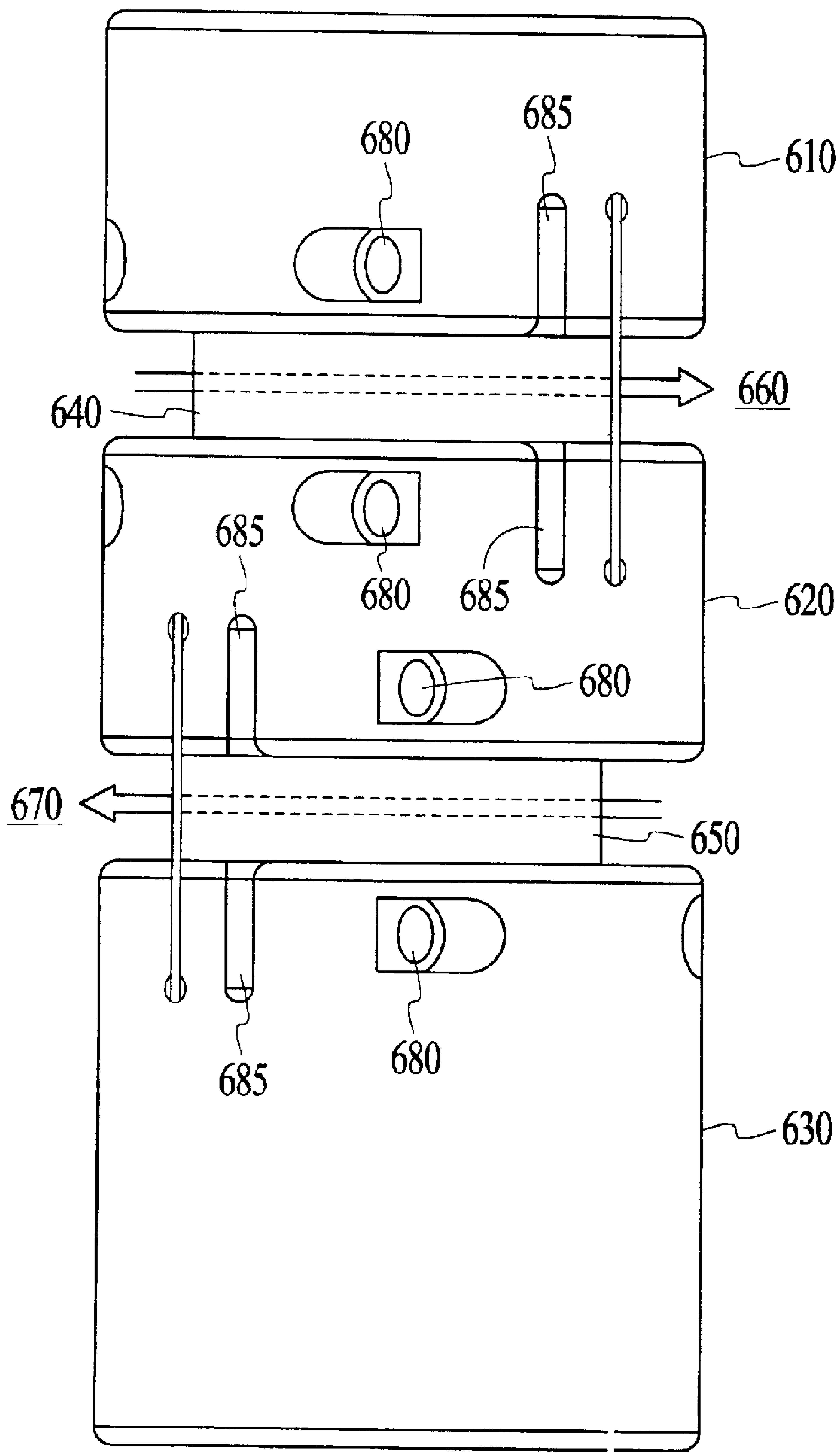

FIG. 7

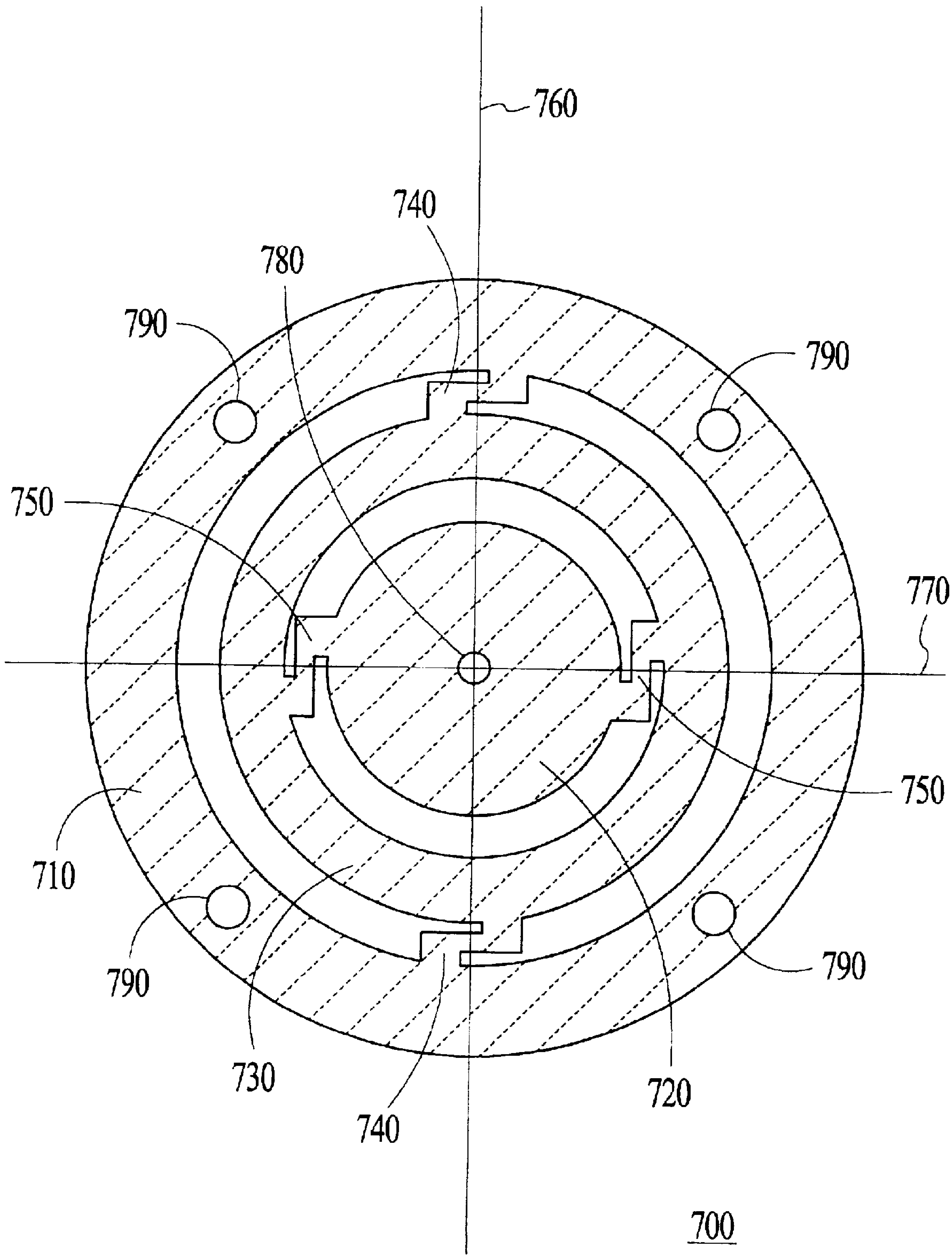

FIG. 8A

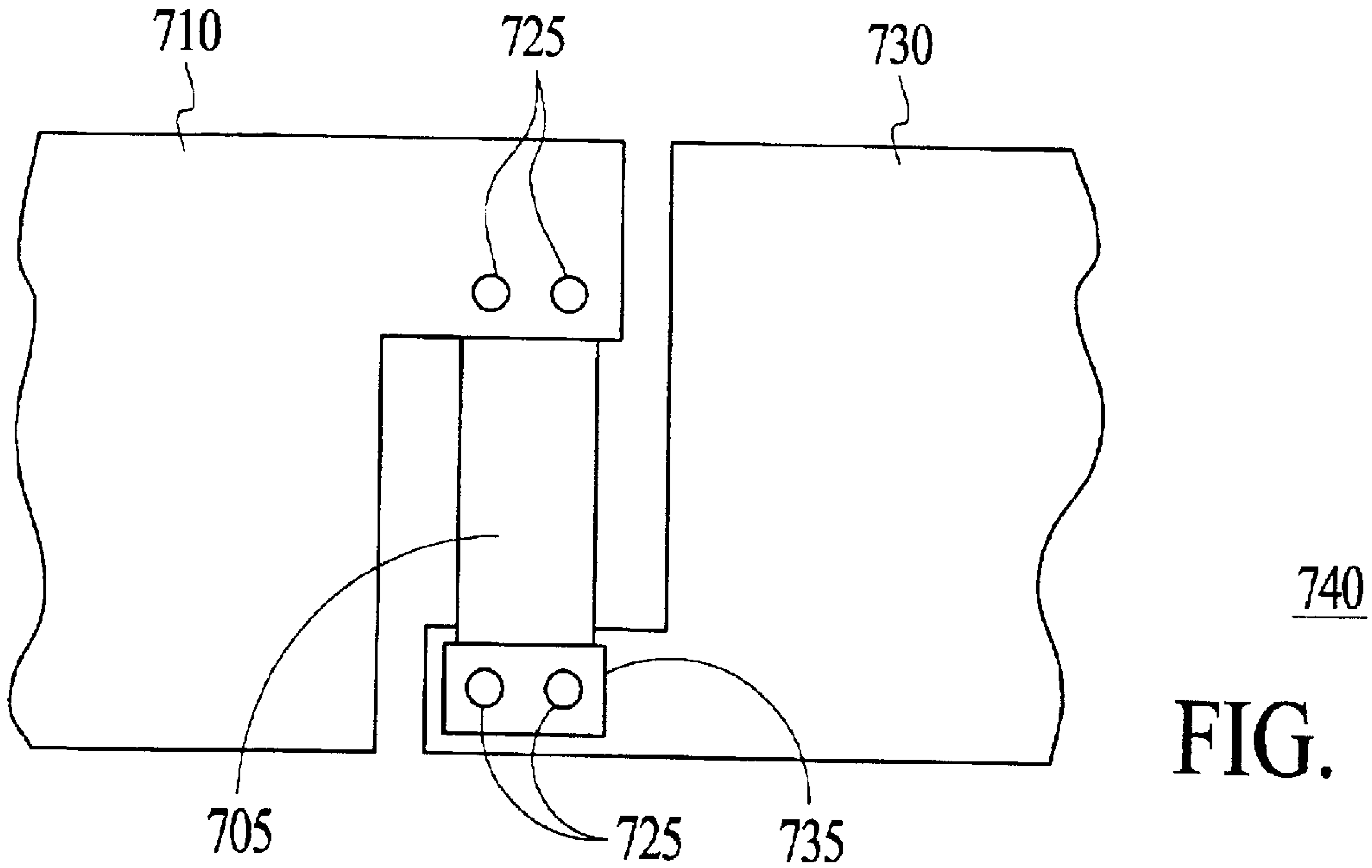

FIG. 8B

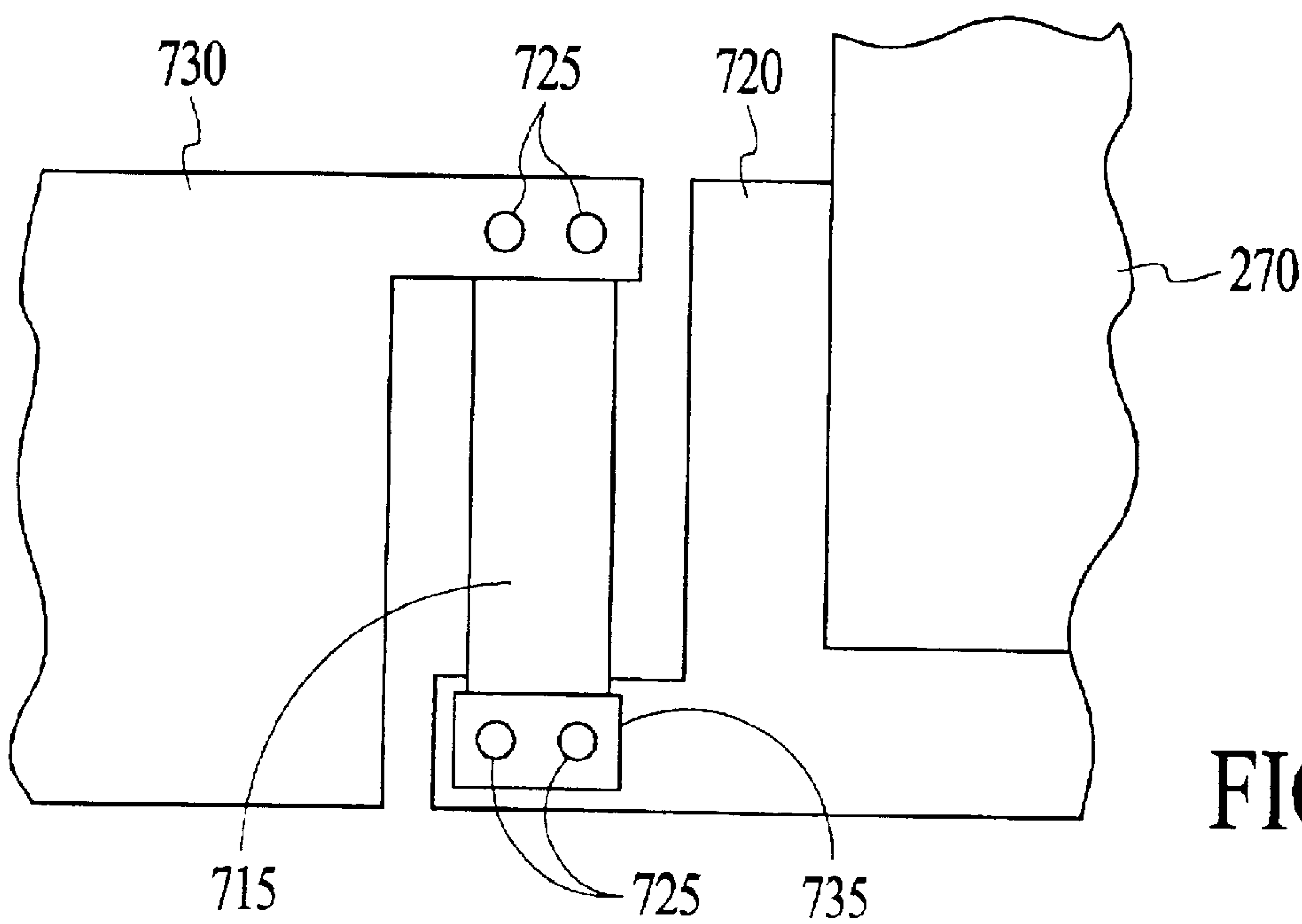

FIG. 8C

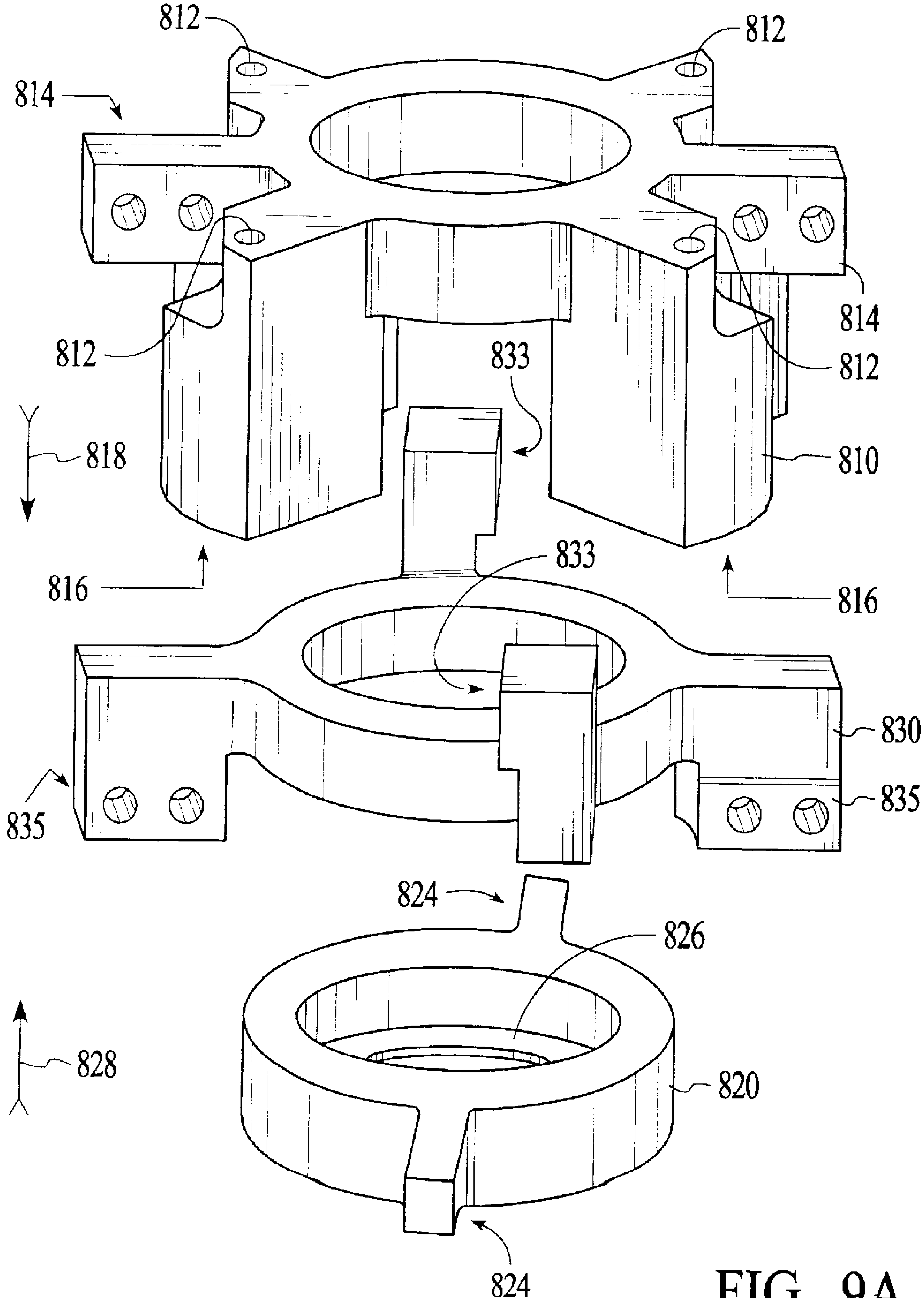
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FIG. 9A

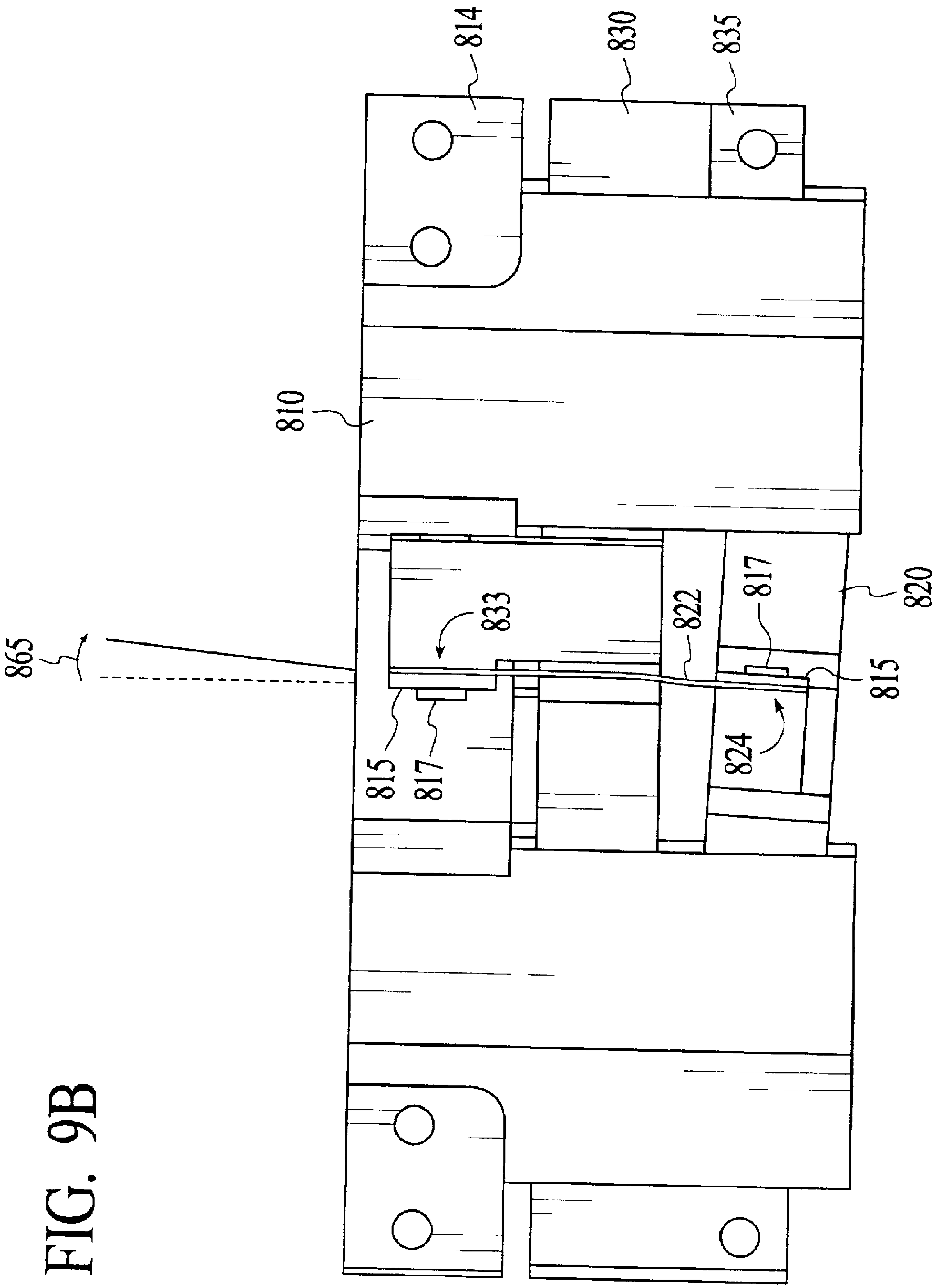

FIG. 9B

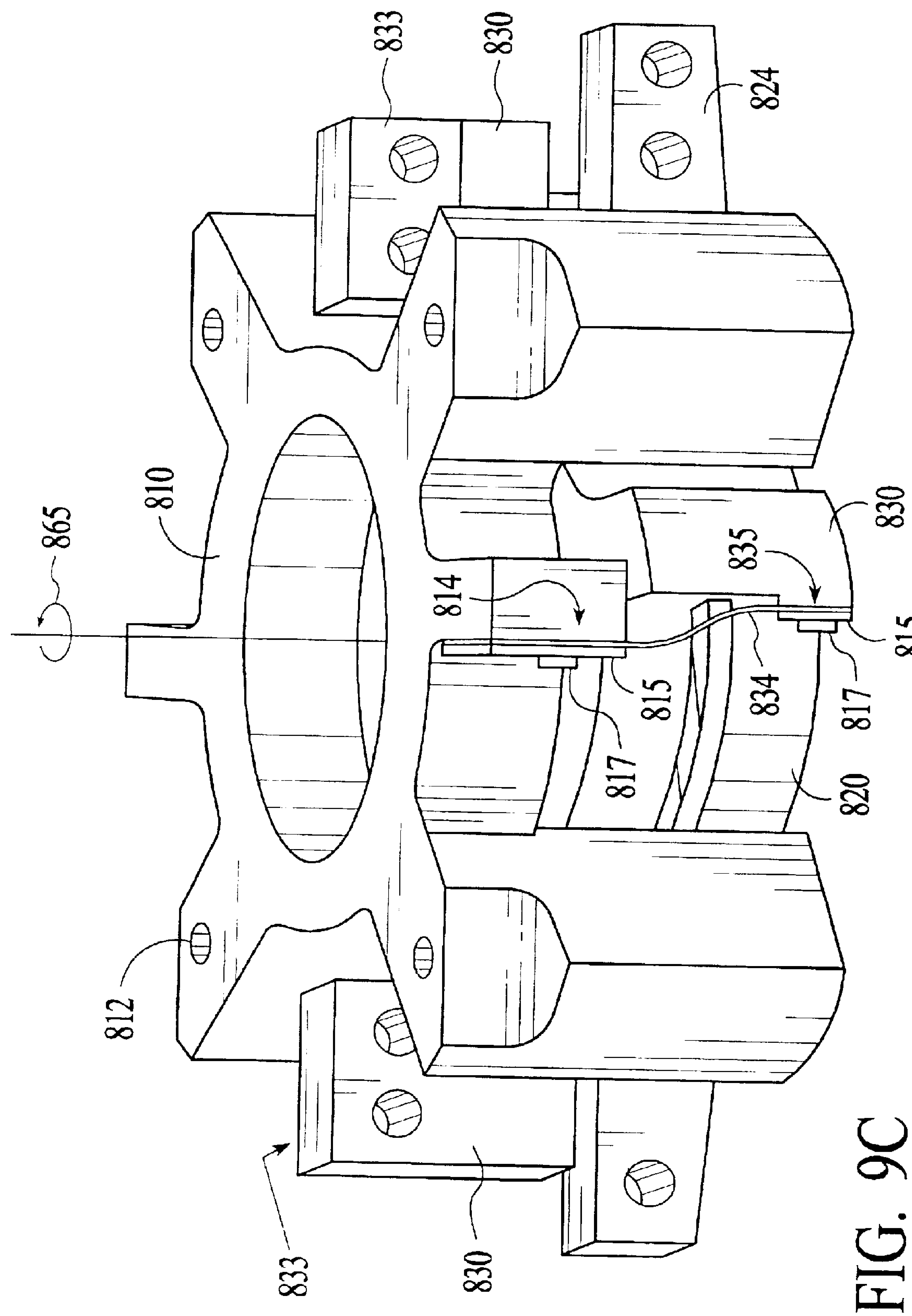
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FIG. 9C

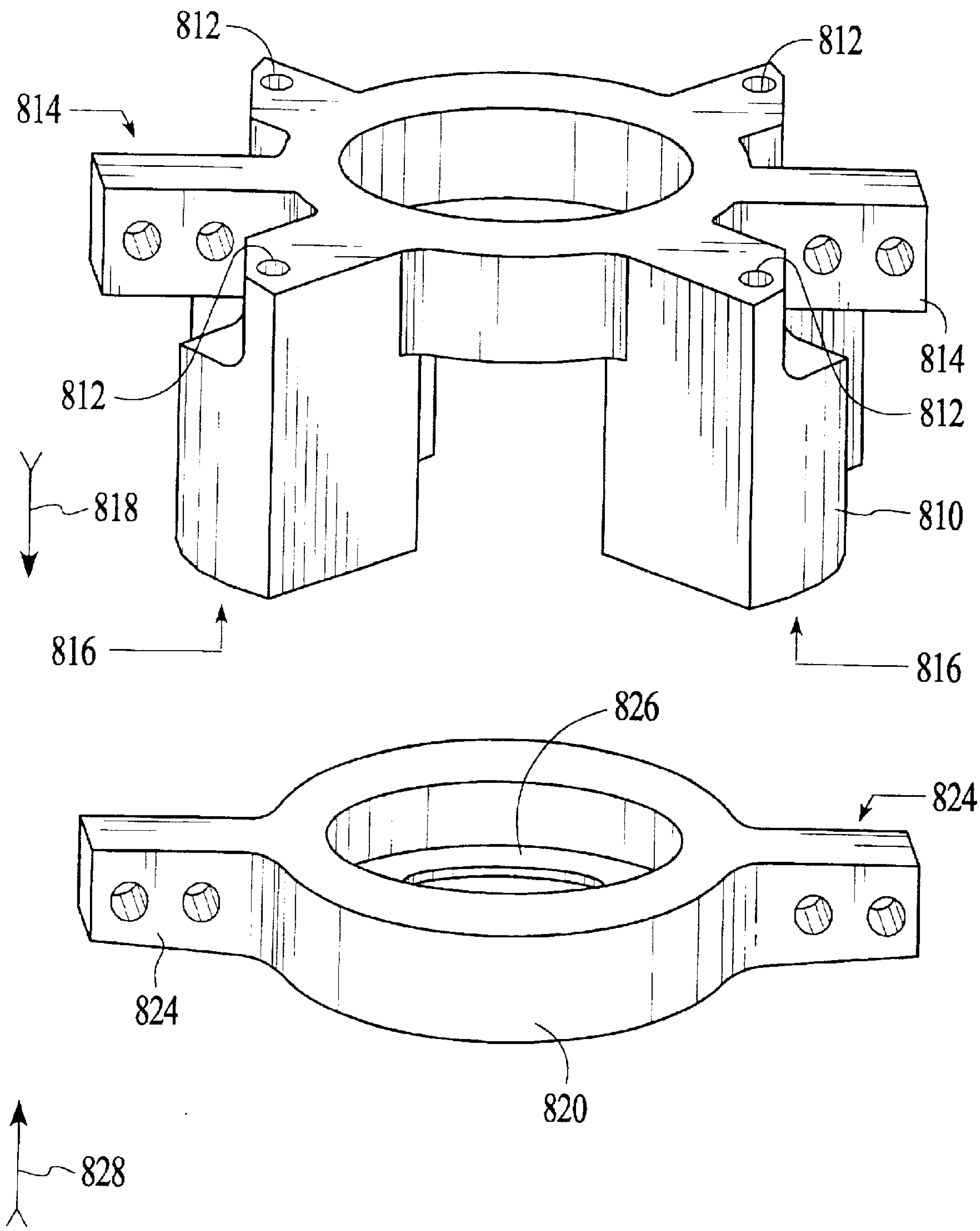

FIG. 10A

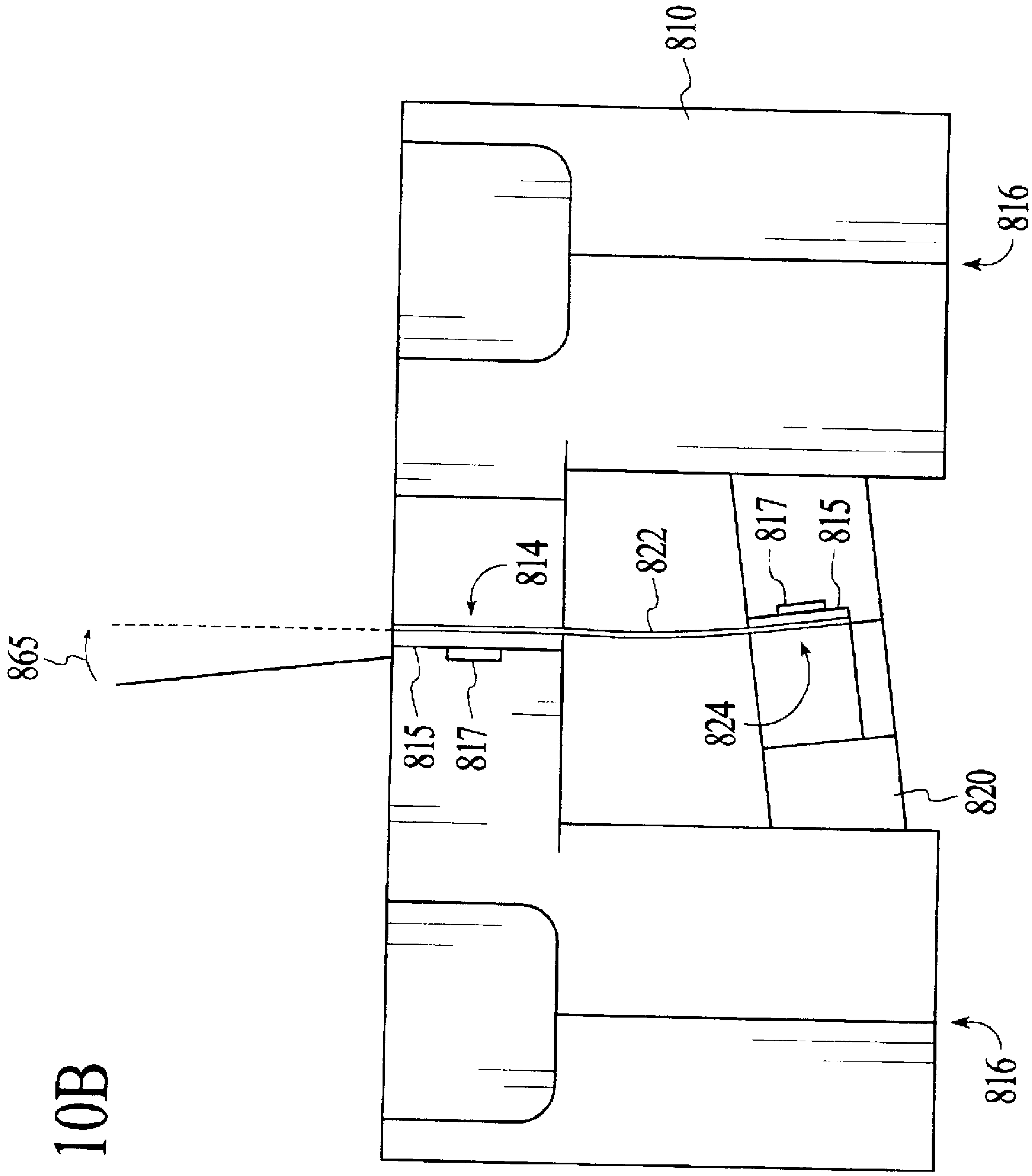

FIG. 10B

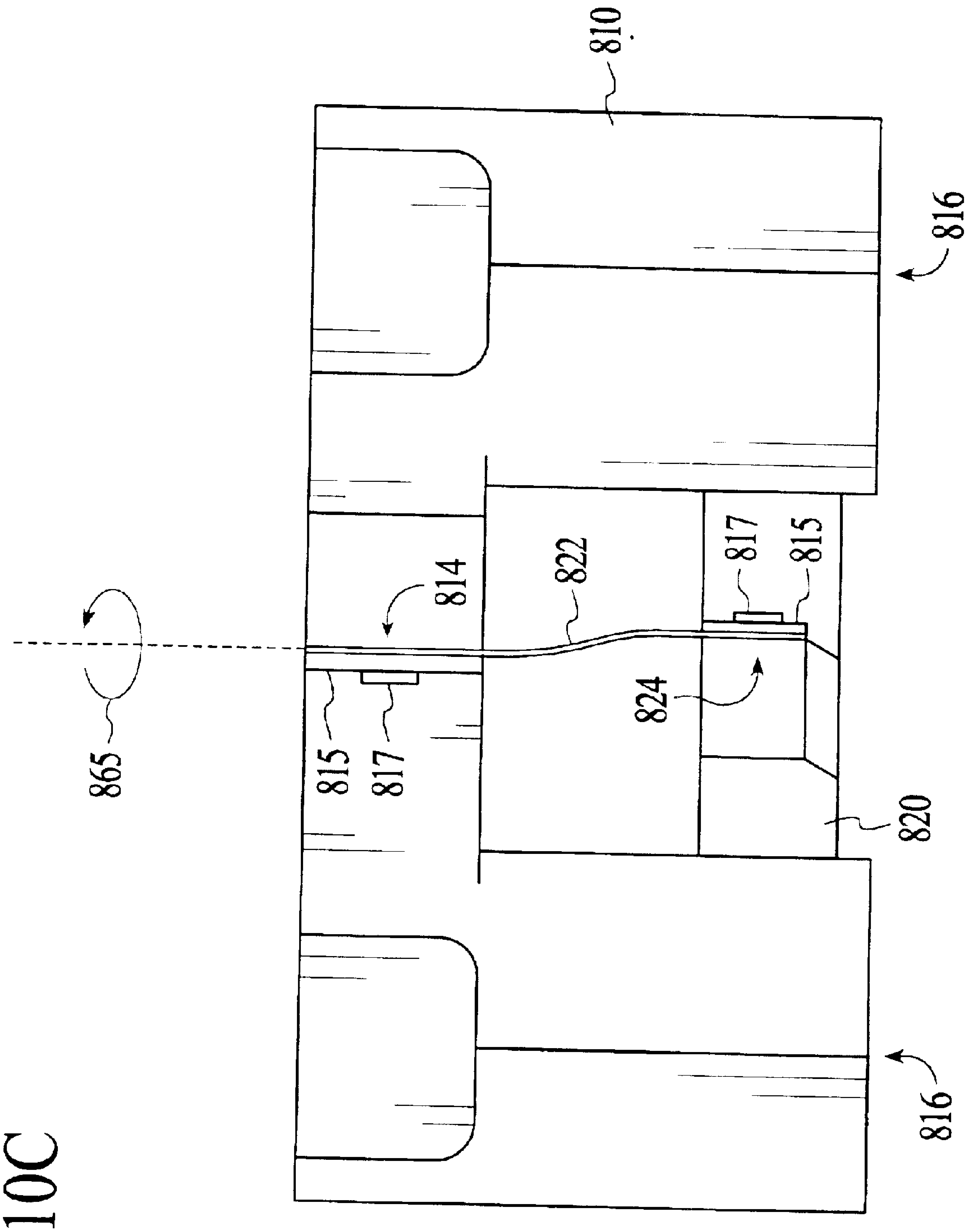

FIG. 10C

PLATFORM POSITIONING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 09/543,265, now U.S. Pat. No. 6,355,994 and 09/543, 283, both filed on Apr. 5, 2000, now U.S. Pat. No. 6,471,435 both of which claim the benefit of U.S. Provisional Application No. 60/163,846 filed Nov. 5, 1999.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the field of control systems for precision stages, and in particular to control systems for stages for use in multi-column charged particle lithography, test and inspection systems.

2. Description of the Related Art

Precision stages find many applications with steadily increasing precision requirements. In semiconductor capital equipment, for example, precision stages are required for carrying wafers during lithography process steps. As the length scales of microcircuit features become smaller, modem lithography moves toward the use of higher resolution techniques, for example phase shift masks, extreme ultraviolet (EUV) systems, and high throughput charged particle beam lithography. With the overall trend toward smaller features, positioning requirements of the wafer (and a stage platform upon which it rests) relative to lithography optics have become increasingly stringent.

Due to the comparative magnitudes of charged particle wavelengths and sub-micron features, charged particle (especially electron) beam lithography is an important technique for realizing sub-micron feature sizes. However, in charged particle beam lithography systems, vacuum and high voltage compatibility is an inherent design complication.

In order to accelerate a charged particle beam, for example an electron beam, particle beam lithography systems typically have electric potential differences (up to 100 kV) between different components. In many designs, a workpiece or wafer is held at a potential close to electrical ground and the electron source is at comparatively higher voltage. However, in some systems, the electron source is operated at a potential close to electrical ground, while the workpiece is held at comparatively higher voltage. Such an electron source is described in U.S. Pat. No. 5,637,951.

A vacuum is also required within the lithography device to allow the propagation of an electron beam. A high vacuum, with pressure of no more than 10-6 Torr, is typically required. Thus, in addition to providing the required precision, a stage for electron beam lithography must be able to sustain high voltage differences between components and be suitable for operation under high vacuum conditions.

In regard to high voltage operability, many prior art precision stages comprise several closely coupled kinematic platforms. An exemplary prior art device of this type is shown in FIG. 1. However, in a system where up to 100 kV potential difference must be held off with no arcing or other undesirable effects, close mechanical coupling of non-insulating components, such as illustrated in FIG. 1, would be inappropriate.

In regard to vacuum compatibility, many prior art stages are inappropriate for use in a high vacuum due to bearing designs that are prone to out-gassing, generating particulates, or otherwise contaminating the vacuum system.

In comparison to other bearing types, flexural bearings are very well-suited for use in vacuum, and allow smooth, precise, predictable motion of the stage. Such properties are discussed in detail by Alexander Slocum, "Precision Machine Design", Prentice Hall, N.J., 1992. However, most prior art flexural bearings are potentially unstable when used as thrust bearings since the flexural joint is prone to distortion or buckling under compressive loads. Thus, in precision stage applications requiring vacuum compatibility, there is a need for multiple degrees of freedom of movement flexural thrust joints.

Further, for positioning systems requiring precision movement and short times to reach a steady-state position (settling times) after each movement, attention must be paid to perturbations that are insignificant for less precise systems. In order to optimize the mechanical stability of the stage under external impulses, vibrations or other mechanical perturbations, most prior art high precision lithography stages utilize massive, high inertia elements. However, while a high inertia system tends to be mechanically stable, the reaction forces associated with moving a massive stage can degrade the accuracy and precision of the relative positioning of the lithography optics and the work platform, unless a long settling time is accepted. A combination of careful isolation of the optics and addition of considerable mass to the optics mounts is required to overcome this problem. The resulting weight and volume of such devices is undesirable. It would be beneficial, then, to have a comparatively low-mass high precision stage that avoids these problems. Furthermore, such a low-mass stage would be well-suited for commercial lithography tools with their high throughput requirements, where frequent large accelerations and decelerations are required for rapid processing of the workpiece.

Therefore, especially for use in charged particle lithography systems, there is a need for stages capable of maintaining high precision alignment with a reference (for example the position of the lithography optics) while being vacuum compatible and capable of sustaining large voltage differences between elements. Such platforms should be continuously and smoothly movable over six degrees of freedom of movement. Such platforms should also be capable of holding workpieces with characteristic lengths of hundreds of millimeters, e.g. 300 mm silicon wafers.

SUMMARY OF THE INVENTION

This invention includes a platform positionin system for precisely positioning and moving a platform, with as many as six degrees of freedom, relative to a support structure. The platform is particularly suitable for carrying silicon wafers. According to aspects of the invention, the platform positioning system comprises: a stage comprising a base, a platform and stage actuators, wherein the platform is coupled to the base and the stage actuators are coupled to the platform, the base and the frame; a frame attached to the base; a support structure mechanically coupled to the frame; stage sensors attached to the support structure, for sensing the position of the platform relative to the support structure; and a current control system coupled to the stage actuators and the stage sensors, whereby the platform is positioned and moved precisely, with respect to the support structure, with at least four degrees of freedom. The frame can be vaccum sealed. Further, the platform can comprises a laser reflective top and side surfaces, which can be formed on one piece of material; this material comprising quartz or glass. The stage sensors can comprise three laser interferometers and three laser triangulators, which determine platform osition by reflecting laser light off the reflective side and top surfaces, respectively. In a preferred embodiment the stage actuators are non-commutated linear electromagnetic motors. The current control system comprises a trajectory generator coupled to a feedforwad controller and a feedback controller, a conversion matrix coupled to stage sensors and the feedback controller, the feedforward controller further coupled to an adder and steering matrix, and a current control system can also include a gravity compensator coupled to the conversion matrix and the adder and steering matrix. Futhermore, the feedforward controller can be an adaptive feedforward controller in which case it is also coupled to the converison matrix. Further, the current control system can also include an predictor coupled to the conversion matrix, for generating an output signal anticipating the actual position of the platform relative to the support structure in real time. In preferred embodiments of the platform positioning systems the stage can be a leg stage, incorporating flexure joints, thus allowing smooth and continuous platform motion. In certain embodiments of the invention the stage is designed to accommodate 300 mm wafers on the platform and to weigh less than 100 lbs.

For use in applications such as charge particle lithography, charged particle optics can be attached to the support structure and mechanically coupled to the frame of the platform positioning system, resulting in a charged particle beam system. The charged particle optics can comprise multiple columns, each column generating at least one charge particle beam. In cerain embodiments of the invention the current control system includes a predictor which sends signals to a deflection system, included in the charged particle optics, allowing more accurate placement of charged particle beams on a moving platform. The platform can comprise a wager chuck. In preferred embodiments, any point on a wafer, placed on the wafer chuck, can be positioned relative to the charged particle optics with an accuracy of at least one micrometer.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** shows a prior art stage.

FIG. **2**A shows a preferred embodiment of the leg stage.

FIG. **2**B shows a cross-section through the leg stage of FIG. **2**A, in the vertical plane containing X–X', and also shows a second platform movement member, a vacuum chamber, and charged particle optics.

FIG. **2**C shows a plan view of the platform, with wafer and wafer chuck removed.

FIG. **3**A shows a diagrammatic plan view of the platform movement member, showing magnet configuration.

FIG. **3**B shows a diagrammatic cross-sectional view of the platform movement member of FIG. **3**A, along A–A', showing relative placement of magnets and coil.

FIG. **3**C shows a plan view of the stage platform, showing the drive coils and a schematic representation of the current control system.

FIG. **3**D shows a plan view of the stage platform, showing the cooling lines and a schematic representation of the cooling circuit.

FIG. **3**E is a schematic illustration of the superposition of the magnets and first coils.

FIG. **4** shows a block diagram of a preferred embodiment of the electrical current control system.

FIG. **5** is a diagrammatic illustration of a preferred embodiment of the stage sensors.

FIG. **6**A is a schematic representation of a raising member.

FIG. **6**B is a diagrammatic illustration of a first design of the raising actuator.

FIG. **6**C is a diagrammatic illustration of a second design of a raising actuator, shown as a side view.

FIG. **6**D is a diagrammatic illustration of a second design of a raising actuator, shown as a top view.

FIG. **7** shows a two degrees of freedom of movement flexural joint.

FIG. **8**A is a diagrammatic plan view of an embodiment of a three degrees of freedom of movement flexural joint.

FIG. **8**B shows a diagrammatic cross-sectional view of the second flexure hinge from FIG. **8**A.

FIG. **8**C shows a diagrammatic cross-sectional view of the first flexure hinge from FIG. **8**A.

FIG. **9**A shows an exploded perspective view of a preferred embodiment of the three degrees of freedom of movement flexural joint.

FIG. **9**B shows a preferred embodiment of the three degrees of freedom of movement flexural joint with tilt of the leg axis.

FIG. **9**C shows a preferred embodiment of the three degrees of freedom of movement flexural joint with rotation about the leg axis.

FIG. **10**A shows an exploded perspective of an embodiment of a two degrees of freedom of movement flexural joint.

FIG. **10**B shows an embodiment of a two degrees of freedom of movement flexural joint with tilt of the leg axis.

FIG. **10**C shows an embodiment of a two degrees of freedom of movement flexural joint with rotation about the leg axis.

DETAILED DESCRIPTION

FIG. **2**A shows a perspective of a preferred embodiment of this invention; various components are not shown, for ease of illustration. In FIG. **2**A, stage **200**, base **220**, first attachment members **230**, platform **240**, wafer chuck **242**, wafer **244**, bottom platform surface **250**, second attachment members **260**, legs **270**, platform axes **280**, raising members **285**, and platform movement members **290** are shown. FIG. **2**B shows a cross-section through the leg stage. In FIG. **2**B, frame **210** (shown here as a vacuum chamber), vacuum pump **215**, base **220**, first attachment members **230**, second attachment members **260**, legs **270**, platform axes **280**, raising members **285**, platform movement members **290**, and charged particle optics **295** are shown. FIG. **2**C shows the platform with wafer and wafer chuck removed. In FIG. **2**C, platform beams **245**, platform actuator carriers **246**, carrier holes **247**, wafer chuck support **248** and leg brackets **249** are shown.

In the embodiment shown in FIG. **2**A, first attachment members **230** are coupled to raising members **285** and to the bottom ends of legs **270**. The raising members are coupled to the base **220**. The legs support platform **240** and the top ends of legs **270** are coupled to bottom platform surface **250** by second attachment members **260**. Platform movement member **290** is coupled to the platform. In preferred embodiments the legs are substantially parallel to each other.

In FIG. **2**B frame **210** is vacuum-sealed and coupled to a laboratory floor, through base **220**. In alternate embodiments, some vibration isolation may be provided between the frame and the laboratory floor. Vacuum pump **215** is connected to vacuum-sealed frame **210**, allowing effective evacuation of the vacuum-sealed frame (reaching high vacuum). Charged particle optics **295** is mechanically coupled to the vacuum-sealed frame **210**. The charged particle optics can be used to generate and control a beam or beams of charged particles, directed onto the stage.

The wafer chuck **242** will require a high voltage supply. Most embodiments will have a high voltage supply (not shown) external to the stage; thus requiring a high voltage connector (not shown) between the stage and supply. In the case where the frame is vacuum-sealed, the connector will need to be vacuum compatible and the high voltage supply may conveniently be placed outside the vacuum-sealed frame. The connector can be attached to the wafer chuck from below in such a way as to avoid contact with the legs **270** during motion and care must be taken when designing the connector to minimize the transfer of mechanical impulses and vibrations along the connector.

In FIG. **2**C the construction of platform **240** is shown in detail for a particular embodiment. The platform actuator carriers **246** and the wafer chuck support **248** are attached to the platform beams **245**. The leg brackets **249** are attached to the wafer chuck support **248**; the legs **270** may be attached to leg brackets **249** by second attachment members **260**.

Stage **200** is a device providing a work platform positionable to high precision. When coupled to a computer control system including position sensors, such as a laser interferometer, stage **200** can provide controllable positioning of platform **240** such that a point on the platform can be positioned to within at least a micrometer relative to a reference position, such as the position of lithography optics **295**. In most embodiments, platform **240** has six degrees of freedom of movement. In reference to the coordinate system shown in FIG. **2**A, the platform may translate along three axes (x, y, z) and rotate about each axis (θ_x, θ_y, θ_z). While the platform has six degrees of freedom of movement, it is noteworthy that the motions of the platform are over a range determined by the length of legs **270**, and the range of movement of platform movement member **290** and raising members **285**. Hereinafter, the stage according to this invention may be referred to equivalently as a 'leg stage', due to its novel legged configuration. Note that in a preferred embodiment the platform movement members **290** principally control movement in x, y and θ_z and the raising members **285** principally control movement in z, θ_x and θ_y.

In FIG. **2**A, legs **270** act as supporting elements for the weight of platform **240**. In addition, the legs are also advantageous for electrical isolation in embodiments of the invention where there are large differences in electrical potential between elements. In embodiments where a high voltage workpiece rests on the platform, the legs may act to isolate the high voltage workpiece from other elements of stage **200** if the legs are constructed of substantially electrically insulating material. In other embodiments, additional electrical isolation of the workpiece may be accomplished by constructing the platform of substantially electrically insulating material, such as alumina-based ceramic; more specifically, the platform beams **245**, platform actuator carriers **246** and wafer chuck support **248** shown in FIG. **2**C may be fabricated of insulating material. Positioning platform movement members **290** away from the center of the platform, where the high voltage workpiece may be, is also an aspect of electrical isolation in a preferred embodiment.

In FIG. **2**A, platform **240** is free to move relative to frame **210**. An aspect of the motion is accomplished with platform movement member **290**.

For lithography applications of stage **200** a wafer chuck **242**, which is part of platform **240**, is used to hold a wafer **244** during lithographic processing.

The use of lightweight materials such as alumina-based ceramic for constructing the stage platform **240** and legs **270**, is an important contribution to achieving a low-mass high precision stage; design is also optimized to reduce weight, for example the alumina legs may be hollow, the alumina platform beams **245** may be 'U' shaped in cross-section and the alumina platform actuator carriers **246** may have carrier holes **247**. The embodiment shown in FIG. **2**C shows such a lightweight design.

FIGS. **3**A–**3**E illustrate platform movement members **290** for a preferred embodiment of this invention. The platform movement members provide controllable planar motion of platform **240** relative to frame **210**. In a preferred embodiment shown in FIGS. **3**A–**3**E, the platform movement members are comprised of four platform actuators, more specifically four electromagnetic platform actuators.

In FIG. **3**A, frame **210**, platform **240**, magnets **330** and magnet supports **335** are shown. FIG. **3**B is a cross-sectional view from the plane AA' of FIG. **3**A. In FIG. **3**B, frame **210**, platform **240**, first coil **310**, cooling channels **325**, magnets **330**, magnet supports **335** and electromagnetic platform actuator **337** are shown. FIGS. **3**C and **3**D show plan views of systems integral to the platform movement member for a preferred embodiment. In FIG. **3**C, platform **240**, current control system **340**, first coils **310** and first coil connecting cables **316** are shown. In FIG. **3**D, platform **240**, cooling channels **325** and cooling system **350** are shown. In FIG. **3**E, one of first coils **310**, first coil connecting cable **316**, magnets **330**, first coil leg **312**, second coil leg **314** and magnet dimension **322** are shown.

In FIGS. **3**A and **3**B magnets **330** are attached to magnet supports **335**, with N and S poles placed so as to form magnetic circuits according to well-known principles; this magnet configuration and magnet support together are referred to as a first magnet assembly. The magnet supports are attached to frame **210**. First coils **310** are attached to platform **240** and are electrically coupled to current control system **340** (see FIG. **3**C). The flow of electrical charge through the first coils in the presence of a magnetic field due to the first magnet assembly results in a Lorentz force (dF=IdlXB, where dF is a differential Lorentz force exerted by magnetic field B on a differential first coil element dl carrying electrical current I) being exerted on the first coils by the magnetic field. Since the first coils are attached to the platform, continuous and finely controllable planar (x, y) motion of the platform relative to the frame may be accomplished by precise control of the electrical currents in selected first coils. Differential control of the electrical currents supplied to the coils may also allow rotation of the platform about the z axis. It is noteworthy that different magnet assemblies and corresponding first coils may contain differently sized magnets and first coils, or carry different electrical currents. The sizes and positioning of the magnets, first coils, and the magnitude of the electrical current flowing through the first coils are determined by the force and travel requirements in a particular direction of motion.

FIG. **3**C illustrates a configuration of first coils **310** on platform **240** according to aspects of this invention. For the particular embodiment in FIG. **3**C, the configuration of first coils **310** minimizes the magnetic field strength at the center of platform **240**. As described above, attention to the magnetic field strength over the platform is important in embodiments where the platform is an element in a charged particle lithography system. In such systems, stray magnetic fields can act to deflect the charged particles and may corrupt desired patterns formed by the charged particles in a resist material; it may be necessary to introduce some magnetic shielding (not shown) to keep stray magnetic field strength within acceptable limits. In embodiments of the leg stage **200** where stray magnetic fields are insignificant, it may be advantageous to arrange the first coils on the platform differently than shown in FIG. **3**C. For example, the first coils could be arranged in a mirror image configuration, such that like-sized coils face each other, rather than being diametrically opposed as in FIG. **3**C; also coils could be arranged so as to minimize the moment about the center of gravity of the stage.

The electrical resistances of first coils **310** dissipate a fraction of the electrical energy supplied to them, converting it to sensible heat. Cooling system **350** removes heat generated by the first coils, maintaining a desired reference temperature at the center of the platform to within better than +/−0.1 degrees Celsius. The cooling system **350** may comprise closed circuit channels for flow of coolant, a pump, and a device for regulating the temperature of the coolant. Coolant channels **325** according to an exemplary embodiment are shown in FIG. **3**D. Other cooling techniques are readily apparent to those skilled in the art.

In most embodiments the current control system **340** and cooling system **350** may conveniently be placed outside the frame **210**. In the case where the frame **210** is vacuum-sealed, the coolant channels **325** and first coil connecting cables **316** will need to be vacuum compatible. The channels and cables can be attached to the wafer chuck from below in such a way as to avoid compromising the motion of legs **270** during movement of the stage. Care must be taken when designing the channels and cables to minimize the transfer of mechanical impulses and vibrations along the channels and cables.

FIG. **3**E shows the superposition of the magnets **330** and first coil **310**. The motive force on the coils is the Lorentz force acting on the electrons flowing in the first and second coil legs. From FIG. **3**E, it is apparent that the Lorentz forces on opposing first coil legs **312** will substantially cancel each other. This is the case since the current paths in the opposing first coil legs, which are acted upon by like magnetic fields, are in opposite directions. Therefore, the range of motion of the coils relative to the magnets is determined by width **322**. It is noteworthy that the exemplary embodiment shown in FIG. **3**E is a non-commutated motor. In applications requiring limited ranges of motion, non-commutated motors are preferred. However, in applications that require much larger ranges of motion, commutated linear electromagnetic motors, which are well-known in the art, may be used.

For embodiments in which the platform movement members are linear actuators, then a minimum of three such actuators will be needed to provide motion with three degrees of freedom, as discussed above.

FIG. **4** shows a block diagram of a preferred embodiment of current control system **340** as an integrated control system for stage **200** (see FIG. **2**A, FIG. **3**C and FIG. **6**B). In FIG. **4**, current control system **340**, trajectory generator **360**, conversion matrix **362**, feedforward controller **364**, feedback controller **366**, gravity compensator **368**, predictor **370**, adder and steering matrix **372**, current amplifiers **374**, stage sensors **380** and stage actuators **390** are shown. The stage actuators comprise platform movement member **290** and raising actuators **430** (see FIG. **2**A).

Current control system **340** comprises a control system that receives stage position data from stage sensors **380** as input and delivers driving electrical currents for stage actuators **390** as output. The direction of information flow is indicated in FIG. **4**.

Current control system **340** receives data input from stage sensors **380**, and converts the data into (x, y, z, θ_x, θ_y, θ_z) coordinates, representing the sensed position of the stage, by conversion matrix **362**. These values are sent to gravity compensator **368**, feedback controller **366** and predictor **370**. Trajectory generator **360** specifies desired coordinates (x, y, z, θ_x, θ_y, θ_z) as a function of time from store values. These sets of values are sent to feedfordward controller **364** and feedback controller **366**.

As described, set of coordinates for the desired and sensed positions are fed into feedback controller **366**, which compares the desired position with the sensed position and calculated corrective signals to adjust the position of the stage. Trajectroy generator coordinates are input to feedforward controller **364**, which determines the platform acceleration and generates corrective signals to drive the platform to the desired coordinates. In particular embodiments, the feedforward controller may be adaptive, in which case input is received from the conversion matrix **362**. Gravity compensator **368** receives sensed coordinates and generates signals compensating for the inverter pendulum behavior of platform **240**. The compensator **368** can be considered as part of the feedforward controller **364**. Predictor **370** receives sensed coordinates and generates signals to a writing deflection system to anticipate the postion of platform **240** so that lithographic patterns can be correctly placed.

In FIG. **4**, if feedforward controller **364** is accurate, then feedback controller **366** will generate null corective signals. Otherwise, corrective control signals are combined and signals sent to current amplifiers **374** are generated by adder and steering matrix **372**. The current amplifiers generate currents proportional to the control signals for driving stage actuators **390**. It is noteworthy that, since the process of position sensing takes time, there is a predictable error between the actual position of platform **240** and its sensed position at any time. This error is overcome by predictor **370** anticipating the position of the platform **240**. Also noteworthy is that current control (as opposed to voltage control) of the stage actuators in particular embodiments may provide vibration isolation for the stage.

FIG. **5** shows a preferred embodiment of stage sensors **380**. In FIG. **5**, laser interferometers **382**, laser beams **384**, reflective side surfaces **385**, reflective top surface **386**, platform center **388**, and laser triangulators **383** are shown. Platform center **388**, where a wafer may be placed, is not reflective. In a preferred embodiment, reflective top and side surfaces **386** and **385**, respectively, are formed of one piece of material such as quartz or Zerodur™ glass and are integral to platform **240** and all interferometers **382** and triangulators **383** are attached to a common support structure (not shown). The support structure, in turn, is rigidly attached to the charged particle optics (see **295** in FIG. **2**B). In a preferred embodiment the one piece of material forming **385** and **386** is relieved on the backside in order to reduce the weight of the stage.

In FIG. **5**, laser interferometers **382** generate laser beams **384**, which are reflected off the reflective side surfaces **385** of wafer chuck **242** (see FIG. **2**A). The reflected laser beam generates an interference pattern upon combination with the incident beam, which allows changes in the position of the platform **240** to be accurately determined. Laser triangulators **383** provide a measure of the absolute distance between the triangulator and the reflective top surface **386** of platform **240**. The platform position is determined relative to the support structure to which all of the interferometers and triangulators are attached, and hence to the charged particle optics.

In order to determine the starting position of the platform in the horizontal plane, from which relative motion is measured using the interferometers, an alignment procedure between the platform and lithography optics must be followed. There are various alignment procedures that are well known to those skilled in the art of semiconductor lithography, that may be used here.

As illustrated in FIG. 2A, platform **240** is attached to base **220** by legs **270** and the base is fixed to frame **210**. In the embodiment shown in FIG. 2A, as platform movement members **290** articulate the platform relative to the frame, a change in an elevation of the platform relative to the base results since the legs have a constant length. To compensate for this change in the platform elevation, stage **200** incorporates platform-raising members. Also, differential actuation of the platform raising members may result in rotations of the platform about the x and y platform axes **280**.

FIG. **6**A is a schematic of an embodiment of a raising member. In FIG. **6**A, one of legs **270**, base **220**, first attachment member **230**, raising member **285**, support element **410**, damping element **420**, and raising actuator **430** are shown. In FIG. **6**A, raising member **285**, support element **410**, damping element **420**, and raising actuator **430** are attached to the base and the attachment member. In one such embodiment the base is coupled to the laboratory floor (not shown).

In the particular embodiment shown in FIG. **6**A, support element **410** provides a supporting force that is dependent on the separation between first attachment member **230** and base **220**. In general, a force provided by the support element may enhance the control performance of the raising actuator by reducing the load that the raising actuator is required to carry. Damping element **420** provides a force in opposition to relative motions of the attachment member and base proportional to a time rate of change of their relative positions. In this embodiment, the support element and the damping element are passive. Raising actuator **430** is an active and controllable element in combination with a computer control system (not shown). FIG. **6**A shows the case where motion is allowed in the z direction and constrained in all other directions. When the raising members are constrained to move linearly, then there will need to be at least 3 legs, with one such raising member attached to each leg, in order to give motion with three degrees of freedom, as described above.

In alternate embodiments, support element **410** may provide a supporting force that is independent of the separation between first attachment member **230** and base **220** (a constant force support). The support element and damping element may also be a single element such as a visco-elastic beam. In a preferred embodiment, the support element and damping element are a single element comprising elastic structures loaded to a degree approaching a point of elastic stability (e.g. a buckled column), as taught in U.S. Pat. No. 5,310,157. A low structural stiffness in this preferred embodiment may also be advantageous with respect to isolation of platform **240** from vibration. Alternative embodiments may consist simply of a raising actuator, a support element and raising actuator in parallel, or a damping element and a raising actuator in parallel.

FIG. **6**B shows an embodiment of the raising actuator where the raising actuator is an electromagnetic raising actuator. In FIG. **6**B, one of legs **270**, base **220**, first attachment member **230**, raising actuator **430**, second magnet support **440**, second magnets **450**, second coil **460**, electrical cables **317** and current control system **340** are shown.

In FIG. **6**B, raising actuator **430** is attached to the base **220** and first attachment member **230**. In one such embodiment, base **220** may be coupled to the laboratory floor (not shown). Second magnets **450** are attached to second magnet support **440**, with N and S poles placed so as to form a magnetic circuit according to well known principles; this magnet configuration and magnet support together are referred to as a first magnet assembly. The magnet support **440** is attached to first attachment member **230**. Second coil **460** is attached to the base and is electrically coupled by electrical cables **317** to current control system **340**. According to well-known principles described above, the electrical currents in the coil result in a Lorentz force being exerted on the attachment member by the magnetic field. Thus, continuous and finely controllable motion of one of legs **270** relative to the base is accomplished by precise control of the electrical currents in the second coil. The control of the electrical currents in the coils is provided as described above (see FIG. **4**). In combination with platform movement member **290**, the raising actuators allow precise positioning and movement of platform **240** (see FIG. **2**).

FIGS. **6**C and **6**D show another embodiment of raising member **285**. In FIGS. **6**C and **6**D, the raising actuator is a voice coil actuator. In FIGS. **6**C and **6**D, base **220**, voice coil magnet **510**, voice coil **520**, shaft **530**, thin beam **540**, rigid support **550**, electrical cables **317** and current control system **340** are shown.

In FIG. **6**C. the raising actuator is attached to base **220** and comprises voice coil magnet **510** and voice coil **520**. The voice coil is attached to shaft **530**. Shaft **530** is coupled to first attachment member **230** (not shown). Thin beams **540** are attached to a rigid support **550**, which is attached to the base. The shaft **530** passes through thin beams **540**, but is not fixed to them.

Referring to FIG. **6**C, voice coil **520** moves in the z direction when an electric current flows through it. The current passing through coil **520** is controlled by current control system **340** in a manner similar to that described above. Movement of the shaft is constrained in all but the z direction by flexible thin beams **540** and rigid support **550**. A spring (not shown) may be incorporated between the voice coil magnet and the thin beams, the spring axis coaxial with shaft **530**.

A preferred embodiment of the raising member is a Nano-k™ vibration isolator model no. SP1014 and serial numbers 317, 318 and 319 fabricated by Minus k Technology, Inc., which is fabricated using the designs and teaching in U.S. Pat. Nos. 5,178,357 5,310,157 5,370,352 5,390,892 5,549,270 5,669,594 5,794,909 and 5,833,204 incorporated by reference herein, combined in parallel with a BEI Electronics moving coil actuator model no. LA25-42-000A, which is fabricated using the designs and teaching in U.S. Pat. No. 5,345,206 incorporated by reference herein. Note that the use of a metallic coil carrier in the moving coil actuator may provide more than the desired amount of damping, due to Eddy current induction in the carrier; in such cases a non-metallic coil carrier can be used to eliminate this undesired damping. This preferred embodiment of the raising member is a very low spring constant support providing horizontal guidance, which also has a very low natural frequency of motion in the vertical direction, hence providing good vibration isolation. This preferred embodiment of the raising member also has an adjustable spring rate for vertical motion, allowing the natural frequency of the stage to be minimized under varying operating conditions. For example, in some embodiments there is an electrostatic force of attraction between the wafer and the charged particle optics; this force varies non-linearly with separation of the wafer and charged particle optics; this can be compensated for by changing the spring rate as the separation varies.

As shown in FIG. 2A, the motion of platform **240** is constrained by first attachment members **230** and second attachment members **260** at opposite ends of legs **270**. In different embodiments of this invention, first attachment members **230** and second attachment members **260** may have either two or three degrees of freedom of movement. In preferred embodiments, the attachment members and second attachment members are flexural joints. Flexural joints are well-known in the art to be capable of smooth, continuous and highly repeatable motion.

FIG. **7** shows a preferred embodiment of a two degrees of freedom of movement flexural joint. The flexural joint shown in FIG. **7** is suitable as a first attachment member **230** or second attachment member **260**. In FIG. **7**, first joint element **610**, second joint element **620**, third joint element **630**, first flexure strip **640**, second flexure strip **650**, first flex axis **660**, second flex axis **670**, flexure strip fastener holes **680** and notches **685** are shown.

In FIG. **7**, flexure strips **640** and **650** are held in place with fasteners (not shown) inserted in holes **680**. The notches **685** run parallel to the grooves into which the flexure strips are inserted; the fasteners apply pressure to the walls of the notches **685**, thereby holding the flexures in place in their grooves with the force distributed over the area of the flexure in contact with the wall of the groove. First joint element **610** and second joint element **620** are coupled by first flexure strip **640**, defining first flex axis **660**. Similarly, second joint element **620** and third joint element **630** are coupled by second flexure strip **650**, defining second flex axis **670**. The first and second flex axes are axes about which hinge-like motion of the joint elements and connecting flex strips may occur. In a preferred embodiment the first and second flex axes are orthogonal. In preferred embodiments, the first joint element is rigidly affixed to bottom platform surface **650** and third joint element **630** is rigidly affixed to one of legs **270**. In preferred embodiments, the first flexure strips and second flexure strips may have a thickness of about 0.010 inches and be made of spring steel, or beryllium/copper alloy, or ASTM grade **304** stainless steel.

As described above, raising actuators **285** are capable of changing the elevation of platform **240** relative to base **210** (see FIG. 2A). To accomplish a raising motion in a preferred embodiment, first attachment members **230** carry a thrusting force. First attachment members **230** may also have three degrees of freedom of movement. A two degrees of freedom of movement flexural bearing such as that illustrated in FIG. **7** may not only lack a desired degree of freedom of movement, but also may be inadequate as a thrust bearing since the flexural joint is prone to distortion or buckling. It is noteworthy, however, that first flexure strip **640** and second flexure strip **650** (see FIG. **7**) may be made stiff and short. This may allow the joint to perform acceptably under compression.

FIG. **8**A shows a diagrammatic plan view of an embodiment of a three degrees of freedom of movement flexural joint. In FIG. **8**A, three degree of freedom of movement flexural joint **700**, first joint element **710**, second joint element **720**, third joint element **730**, second flexures **740**, first flexures **750**, second flex axis **760**, first flex axis **770**, third flex axis **780**, and fasteners **790** are shown. Note that the first and second flex axes are axes about which hinge-like motion of the joint elements and associated flexures may occur; rotation about the third flex axis is due to twisting of either the first, second or first and second flexures.

In FIG. **8**A, first joint element **710** and third joint element **730** are coupled by second flexures **740**. Likewise, third joint element **730** and second joint element **720** are coupled by first flexures **750**. This results in three degrees of freedom of movement for rotations about the second flex axis **760**, first flex axis **770**, and third flex axis **780**, which in this embodiment are all orthogonal. It is noteworthy that the three degrees of freedom of movement flexural joint according to this invention comprises only two flexure hinges. In a preferred embodiment, the three degree-of-freedom of movement flexural joint may be fastened to base **220** with fasteners **790** and rigidly affixed to one of legs **270** (see FIG. 2A). Note that the first joint element **710** may be spaced from the base to which it is attached in order to allow hinging motion of the joint (not shown).

FIG. **8**B and FIG. **8**C show cross-sectional views of one of second flexure **740** and first flexure **750**, respectively. In FIG. **8**B and FIG. **8**C, first joint element **710**, second joint element **720**, third joint element **730**, second flexure strip **705**, first flexure strip **715**, fasteners **725**, caps **735** and one of legs **270** are shown.

In FIG. **8**B, first joint element **710** and third joint element **730** are coupled by second flexure strip **705**. The second flexure strip is attached to the first and third joint elements by strip fasteners **725**, forming second flexure **740**. The cap **735** is used to spread the force from the fasteners evenly over the end of the flexure. Similarly, FIG. **8**C shows second joint element **720** and third joint element **730** coupled by first flexure strip **715**. The first flexure strip is attached to the second and third joint elements by strip fasteners **725**, forming first flexure **750**. The cap **735** is used to spread the force from the fasteners evenly over the end of the flexure. It can be appreciated from FIG. **8**B and FIG. **8**C that the second flexure strips **705** and first flexure strips **715** undergo tensile stresses when three degrees of freedom of movement flexural joint **700** transmits thrust to leg **270** from raising member **285** attached to first joint element **710**. It is noteworthy in FIG. **8**B and FIG. **8**C that the lengths, stiffness and other characteristics of the first and second flexure strips may be different within a particular embodiment. In preferred embodiments, the flexure strips have a thickness of about 0.010 inches and may be made of spring steel, or beryllium/copper alloy, or ASTM grade **304** stainless steel.

FIG. **9**A shows an exploded perspective view of a preferred embodiment of the three degrees of freedom of movement flexural joint. In FIG. **9**A, first joint element **810**, fastener clearance holes **812**, first flexure strip attachment surfaces **814**, first load bearing surface **816**, first direction **818**, second joint element **820**, second flexure attachment surfaces **824**, second load bearing surface **826**, second direction **828**, third joint element **830**, upper third flexure attachment surfaces **833** and lower third flexure attachment surfaces **835** are shown. Flexure strips and fastening means are omitted from FIG. **9**A for the sake of clarity.

In a typical embodiment, first joint element **810** is coupled to raising member **285** (see FIG. 2A). Second joint element **820** is coupled to one of legs **270** and also to third joint element **830** by two first flexure strips. The third joint element **830** is coupled by two second flexure strips to the first joint element **810**. The leg **270** coupled to the second joint element **820** passes through the centers of each of the joint elements. All flexure strips are secured on flexure strip attachment surfaces **814**, **824**, **833** and **835**. The first load bearing surface **816** is the bottom surface of first joint element **810**; the load bearing surface contacts raising member **285** in a typical embodiment. The first direction **818** is the direction normal to the first load bearing surface. The second load bearing surface **826** is the recessed surface of second joint element **820**, upon which leg **270** sits in a typical embodiment. The second direction **828** is the direction normal to the second load bearing surface. The second direction is opposite to the first direction.

FIG. **9**B shows a preferred embodiment of the three degrees of freedom of movement flexural joint with tilt of the leg axis. In FIG. **9**B, first joint element **810**, second joint element **820**, third joint element **830**, first flexure strip attachment surface **814**, caps **815**, fasteners **817**, first flexure strips **822**, second flexure strip attachment surface **824**, upper third flexure attachment surface **833**, lower third flexure attachment surface **835** and leg axis **865** are shown. Leg **270** and second flexure strips **834**, along with their caps and fasteners, are omitted for the sake of clarity.

In FIG. **9**B, the joint elements are connected as described above for FIG. **9**A. In addition, first flexure strip **822** is fastened on second flexure strip attachment surface **824** and upper third flexure attachment surface **833** by caps **815** and fasteners **817**. Note that the second and third joint elements are connected by two first flexure strips, diametrically opposed (see FIG. **9**A); only one of the first flexure strips can be seen in FIG. **9**B.

FIG. **9**B illustrates a degree of freedom of movement of the joint. As first flexure strips **822** bend, second joint element **820** tilts. Note that this motion results in movement of leg axis **865** as shown. (Note that due to the nature of flexure strip distortion under load, there may be some displacement of one joint element with respect to the next in addition to the tilt described above.) Similarly, a second degree of freedom of movement is due to bending of the second flexure strips (not shown).

FIG. **9**C shows a preferred embodiment of the three degrees of freedom of movement flexural joint with rotation about the leg axis **865**. In FIG. **9**C, first joint element **810**, second joint element **820**, third joint element **830**, fastener clearance holes **812**, first flexure strip attachment surface **814**, caps **815**, fasteners **817**, second flexure attachment surface **824**, upper third flexure attachment surface **833**, second flexure strips **834**, lower third flexure strip attachment surface **835** and leg axis **865** are shown. Leg **270** and first flexure strips **824**, along with their caps and fasteners, are omitted for the sake of clarity. Elements shown in FIG. **9**C are as in FIGS. **9**A and **9**B.

In FIG. **9**C, the joint elements are connected as described above for FIG. **9**A. In addition, second flexure strip **834** is fastened on first flexure strip attachment surface **814** and lower third flexure attachment surface **835** by caps **815** and fasteners **817**. Note that the first and third joint elements are connected by two second flexure strips, diametrically opposed (see FIG. **9**A); only one of the second flexure strips can be seen in FIG. **9**C.

FIG. **9**C illustrates a third degree of freedom of movement of the joint. As second flexure strips **834** bend and twist, for example as a reaction to a torque about leg axis **865**, there is rotational motion of second joint element **820** about leg axis **865**. (Note that due to the nature of flexure strip distortion under load, there may be some displacement of one joint element with respect to the next in addition to the rotation described above.)

Thus, as illustrated in FIG. **9**B and FIG. **9**C, the joint has three degrees of freedom of movement. It is noteworthy in the above that stiffness of the joint may be changed by altering the lengths or material properties of the flexure strips. Note also that the rotational movement of the joint will occur by twisting and bending of both pairs of flex strips; although, the relative amount of twisting and bending will depend on the lengths and stiffnesses of the two pairs of flexure strips. In the preferred embodiment most of the twisting occurs in the longer second flexure strips (both sets of strips having the same stiffness).

FIGS. **9**A–**9**C show a preferred embodiment of the three degrees of freedom of movement flexural joint. In comparison to the embodiment shown in FIG. **8**A where the joint elements are both concentric and coaxial, the joint elements in this preferred embodiment are coaxial, but not concentric. This contributes to freedom of rotation about the leg axis by allowing for longer flexure strips. For a given flexibility about the leg axis, the preferred embodiment shown in FIGS. **9**A–**9**C may be lighter and more compact than the embodiment shown in FIG. **8**A, where the joint elements are both concentric and coaxial. Also, for some applications it may be desirable to have both first attachment members **230** and second attachment members **260** (see FIG. 2A) with three degrees of freedom of motion and the configuration of the flexural joint shown in FIGS. **9**A–**9**C.

The general design concept used for the three degrees of freedom of motion joint shown in FIGS. **9**A–**9**C can be simplified to give a two degrees of freedom of motion joint; this two degrees of freedom of motion joint is shown in FIGS. **10**A–**10**C. This joint can be used where only two degrees of freedom of motion are required.

FIG. **10**A shows an exploded perspective view of an embodiment of the two degrees of freedom of movement flexural joint. In FIG. **10**A, first joint element **810**, fastener clearance holes **812**, first flexure strip attachment surfaces **814**, first load bearing surface **816**, first direction **818**, second joint element **820**, second flexure attachment surfaces **824**, second load bearing surface **826** and second direction **828**, are shown. All flexure strips are secured on flexure strip attachment surfaces **814** and **824**. (Flexure strips and fastening means are omitted from FIG. **10**A for the sake of clarity.) The first load bearing surface **816** is the bottom surface of first joint element **810**. The first direction **818** is the direction normal to the first load bearing surface. The second load bearing surface **826** is the recessed surface of second joint element **820**. The second direction **828** is the direction normal to the second load bearing surface. The second direction is opposite to the first direction.

FIG. **10**B shows an embodiment of the two degrees of freedom of movement flexural joint with tilt of the leg axis. In FIG. **10**B, first joint element **810**, second joint element **820**, first flexure strip attachment surface **814**, caps **815**, fasteners **817**, first flexure strips **822**, second flexure strip attachment surface **824** and axis **865** are shown.

In FIG. **10**B, the joint elements are connected as described above for FIG. **10**A. In addition, first flexure strips **822** are fastened on second flexure strip attachment surfaces **824** and first flexure strip attachment surfaces **814** by caps **815** and fasteners **817**. Note that the first and second joint elements are connected by two first flexure strips, diametrically opposed (see FIG. **10**A); only one of the first flexure strips can be seen in FIG. **10**B.

FIG. **10**B illustrates a degree of freedom of movement of the joint. As first flexure strips **822** bend, second joint element **820** tilts. Note that this motion results in movement of axis **865** as shown. (Note that due to the nature of flexure strip distortion under load, there may be some displacement of one joint element with respect to the next in addition to the tilt described above.)

FIG. **10**C shows an embodiment of the two degrees of freedom of movement flexural joint with rotation about the axis **865**. In FIG. **10**C, first joint element **810**, second joint element **820**, fastener clearance holes **812**, first flexure strip attachment surfaces **814**, caps **815**, fasteners **817**, second flexure attachment surfaces **824**, first flexure strips **822** and axis **865** are shown. Elements shown in FIG. **10**C are as in FIG. **10**B.

FIG. **10**C illustrates a second degree of freedom of movement of the joint. As first flexure strips **822** bend and twist, for example as a reaction to a torque about axis **865**, there is rotational motion of second joint element **820** about axis **865**. (Note that due to the nature of flexure strip distortion under load, there may be some displacement of one joint element with respect to the next in addition to the rotation described above.) Note that the first and second joint elements are connected by two first flexure strips, diametrically opposed (see FIG. **10**A); only one of the first flexure strips can be seen in FIG. **10**C.

Thus, as illustrated in FIG. **10**B and FIG. **10**C, the joint has two degrees of freedom of movement. It is noteworthy in the above that stiffness of the joint may be changed by altering the length or material properties of the flexure strips.

FIG. **2**B shows a charged particle beam lithography system which is comprised of an embodiment of the present invention coupled with a vacuum system (vacuum-sealed frame **210** and vacuum pump **215**) and a charged particle beam generator (charged particle optics **295**). The charged particles could be electrons in a preferred embodiment or ions in other embodiments.

In FIG. **2**B, the vacuum system maintains a gas density within the vacuum-sealed frame that allows a charged particle beam to propagate without significant charged particle scattering. The charged particle beam lithography system generates and controls at least one charged particle beam for writing patterns on a semiconductor wafer as well as controlling the position of the at least one charged particle beam relative to the wafer. An aspect of positioning of the at least one charged particle beam relative to the wafer includes articulating elements of stage **200** according to this invention. Note that the stage of this invention is particularly well suited to a multiple column, multiple electron beam lithography system (each column having multiple electron beams), where columns are distributed over the area of the wafer, allowing lithography with only minimal movement of the stage.

The top surface of the platform should be capable of accommodating a semiconductor wafer with a diameter of at least 100 mm, and preferably a diameter of 300 mm

In a preferred embodiment, a low-mass high precision stage capable of holding a 300 mm wafer weighs less than 100 lbs. This is achieved by optimizing the engineering design and using lightweight materials; the use of alumina-based ceramic for the platform **240** and legs **270** and relieving the backside of the reflective top (**386**) and side surfaces (**385**) of the platform are described above.

Preferred embodiments of the stage as described above are operated with the wafer at 50 kV relative to the frame, and could be operated at 120 kV or higher.

The foregoing descriptions of various embodiments of the invention have been presented for purposes of illustration and description. It is not intended to limit the invention to the precise forms disclosed. Many modifications and equivalent arrangements will be apparent.

What is claimed is:

1. A platform positioning system comprising:

a frame;

a stage comprising a base, a platform and stage actuators, wherein said stage actuators are coupled to said platform, said base and said frame, and wherein said frame is attached to said base;

a support structure mechanically coupled to said frame;

stage sensors attached to said support structure, said stage sensors being configured to sense the position of said platform relative to said support structure; and

a current control system coupled to said stage actuators and said stage sensors, said control system being capable of controlling precise positioning and movement of said platform relative to said support structure, said control system comprising a conversion matrix coupled to said stage sensors into, said conversion matrix being capable of converting signals from said stage sensors into coordinates representing the sensed position of said platform relative to said support structure, said control system further comprising a predictor coupled to the output of said convension matrix, said predictor being capable of generating an output signal anticipating the actual position of said platform relative to said support structure from coordinates provided by said conversion matrix.

2. The platform positioning system of claim **1**, wherein said frame is vacauum-sealed.

3. The platform positioning system of claim **1**, wherein said platform comprises a laser reflective top surface and laser reflective side surfaces.

4. The platform positioning system of claim **3**, wherein said laser reflective top surface and said laser reflective side surfaces are formed on one piece of material.

5. The paltform positioning system of claim **4**, wherein said material comprises quartz or glass.

6. The platform positioning system of claim **3**, wherein said stage sensors comprise three laser interferometers facing said laser reflective side surfaces and three laser triangulaters facing said laser reflective top surface.

7. The platform positioning system of claim **1**, wherein each stage actuator comprises a non-commutated linear electromagnetic motor.

8. The platform positioning system of claim **1**, wherein said current control system further comprises:

a trajectory generator configured to provide desired platform coordinates as a function of time:

a feedforward controller, the input of said feedforward controller being coupled to the output of said trajectory generator, said feedforward controller being capable of generating signals to drive said platform to desired coordinates received from said trajectory generator;

a feedback controller, the input of said feedforward controller being coupled to output of said trajectory generator and the output of said conversion matrix, said feedback controller being capable of comparing desired and sensed coordinates for said platform and generating corrective signals to drives said platform to said desired coordinates;

an adder and steering matrix, the input of said adder and steering matrix being coupled to the output of said feedforward controller and the output of said feedback controller, said adder and steering matrix being capable of combining drive signal; and

current amplifiers, the input of said current amplifiers being coupled to the output of said adder and steering matrix, said current amplifiers being capable of generating currents proportional to drive signals, for driving sais stage actuators.

9. The platform positioning system of claim **8**, wherein said current control system further comprises a gravity compensator, the input of said gravity compensator being coupled to the output of said conversion matrix and the output of said gravity compensator being coupled to the input of said adder and steering matrix, said gravity compensator being capable of generating drive signals compensating for the inverted pendulum behavior of said platform and wherein said stage further comprises at least three substantially parallel legs coupled to said base and the bottom surface to said platform.

10. The platform positioning system of claim **8**, wherein said feedforward controller is an adaptive feedforward controller and the input of said feedforward controller is further coupled to the output of said conversion matrix.

11. The platform positioning system of claim **1**, wherein said stage further comprises means for smooth, precise and predictable movement.

12. The platform positioning system of claim **1**, wherein said platform has a top surface capable of accommodating a wafer with a diameter of 300 mm.

13. The platform positioning system of claim **12**, wherein the weight of said stage is less than 100 lbs.

14. A charged particle beam system comprising:

a frame, wherein said frame is vacuum sealed;

charged particle optics mechanically coupled to said frame;

a writing deflection system;

a stage positioned below said charged particle optics, said stage comprising a base, a platform and stage actuators, wherein said stage actuators are coupled to said platform, said base and said frame and wherein said frame is attached to said base;

stage sensors rigidly coupled to said charged particle optics, said stage sensors being configured to sense the position of said platform relative to said charged particle optics; and

a current control system coupled to said stage actuators and said stage sensors, said control system being capable of controlling precise positioning and movement of said platform relative to said charged particle optics, said control system comprising a conversion matrix coupled to said stage sensors, said conversion matrix being capable of converting signals from said stage sensors into coordinates representing the sensed position of said platform relative to said charged particle optics, said control system further comprising a predictor coupled to the output of said conversion matrix, the output of said predictor being coupled to said writing deflection system, said predictor being capable of generating an output signal anticipating the actual position of said platform relative to said charge particle optics from coordinates provided by said conversion matrix, whereby a lithographic pattern can be correctly placed on a wafer attached to said platform.

15. The charge particle beam system of claim **14**, wherein said charged particle optics comprises multiple columns, each column generating at least one charged particle beam.

16. The charged particle beam system of claim **15**, wherein said charged particle beam is an electron beam.

17. The particle beam system of claim **14**, wherein said stage actuators comprise platform movement members coupled to said platform and said frame, and raising actuators coupled to said platform and said base.

18. The charged particle beam system of claim **14**, wherein said current control system further comprises:

a trajectory generator configured to provide desired platform coordinates as a function of time;

a feedforward controller, the input of said feedforward controller being coupled to the output of said trajectory generator, said feedforward controller being capable of generating signals to drive the platform to desired coordinates received from said trajectory generator;

a feedback controller, the input of said feedback controller being coupled to the output of said trajectory generator and the output of said conversion matrix, said feedback controller being capable of comparing desired and sensed coordinates for said platform and generating corrective signals to drive said platform to said desired coordinates;

an adder and steering matrix, the input of said adder and steering matrix being coupled to the output of said feedforward controller and the output of said feedback controller, said adder and steering matrix being capable of combining drive signals; and

current ampilifers, the input of said current amplifiers being coupled to the output of said adder and steering matrix, said current amplifiers being capable of generating currents proportional to drive signals, for driving said stage actuators.

19. The charged particle beam system of claim **14**, wherein said platform comprises a wafer chuck.

20. The charged particle beam system of claim **19**, wherein any point on a wafer placed on said wafer chuck can be positioned relative to said charged particle optics with an accuracy of at least one micrometer.

21. The platform positioning system of claim **1**, wherein said stage further comprises at least three substantially parallel adjustble limbs coupled to said base and the bottom surface of said platform, each limb comprising:

a leg;

one of said stage actuators, the bottom of said actuator being coupled to said base;

a first flexural joint connecting the top end of said leg and the bottom surface of said platform.

22. The platform positioning system of claim **21**, wherein both said first and second flexural joints are flexural thrust joints, said flexural thrust joint being configured to provide smooth, precise and predictable motion when under a compressive load.

23. A platform positioning system comprising:

a platform;

stage sensors configured to sensor the position of said platform;

a conversion matrix coupled to said stage sensors, said conversion matrix beign capable of converting signals from said stage sensors into coordinates representing the sensed position of said platform;

a predictor coupled to the output of said conversion matrix, said predictor being capable of generating an output signal anticipating the actual position of said platform from coordinates provided by said conversion matrix.

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